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SHIPBUILDING ALIGNMENT WITH LASERS

TODD SHIPYARDS CORPORATION

PREPARED FOR
MARITIME ADMINISTRATION

APRIL 1974

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F O R W A R D

This manual is the end product of one of the many research projects being performed under the National Shipbuilding Research Program. The Program is a cooperative, cost-shared effort between the Maritime Administration's Office of Advanced Ship Development and the shipbuilding industry. The objective, as conceived by the Ship Production Committee of The Society of Naval Architects and Marine Engineers, emphasizes productivity.

The research effort contained herein is one of the nine outfit Category projects being managed and cost shared by Todd Shipyards Corporation. It was performed in response to the task statement titled "Optical Lasers in Shipbuilding". The work was assigned by subcontract to the Boeing Company, after evaluation of several proposals.

Mr. A. K. Creighton of Boeing's Applied Optics Group, Manufacturing Research and Development was the Senior Engineer on the project.

Mr. L. D. Chirillo, Todd Shipyards Corporation, Seattle Division was the Program Manager.

Special acknowledgement is due also to the following for "their constructive criticism of the manual in its draft form: Mr. F. T. Braithwaite, Norfolk Naval Shipyard; Mr. Arthur B. Millay, Sun Shipbuilding and Dry Dock Company; Mr. W. G. Lockett, Mr. Ed "Basta, Mr. Wayne OB. Rammell, Newport News Shipbuilding and Dry Dock Company; Mr. Hans Ruehsen, Mr. John A. Williamson,...Mr." Jack Schaefer, Bethlehem Steel corporation, Sparrows Point; Mr. V. Shrinivasan;" Seatrain Shipbuilding Corporation.

EXECUTIVE SUMMARY

The basic objective of this manual was to present actual experience in applying lasers for shipbuilding alignment and to identify areas where lasers could be advantageous over other systems for either alignment or measurement. Inquiries in numerous shipyards disclosed that there were a few successful and significant applications, some abortive attempts and virtually no meaningful cost data related to specific alignment functions.

Those attempts which were not successful are attributed to not having purchased the right laser device for the job in hand and to not recognizing that maintaining a power limit; for safety, inhibits use over long ranges in bright daylight.

The initial draft for this manual emphasized detailed alignment procedures. An advisory board, consisting of alignment people from various shipyards, recommended that dependence be placed upon each shipyard's specific procedures and that the manual serve to facilitate understanding of the laser devices and accessories so that they could be readily adopted. In place of procedures they recommended liberal use of illustrations to suggest applications. This technique was also believed to be better for other reasons.

Lasers are inherently better for alignment measurements that are precise and repeatable over long distances because they do not depend on human vision to detect and identify the amount of misalignment. The visual laser beam minimizes the skill required for establishing planes and angles. But, neither of these characteristics are required in all shipbuilding applications. Lasers are better for virtually all machinery alignment: Yet, conventional optics are sufficiently accurate at short ranges and sometimes preferred in very bright light. Thus, the general replacement of existing optical equipment with lasers is not recommended. Procurement costs are about the same and many accessories are interchangeable. Therefore, when supplementing existing alignment equipment it would be prudent to procure lasers in order to allow alignment people to select and use that which is best for the immediate task in hand.

This manual provides guidance with which to select and specify lasers that serve the suggested applications. Moreover, it provides sufficient knowledge for someone already experienced in alignment techniques to adapt lasers to existing procedures and to implement new procedures. It can be used to convey and understanding of lasers and their accessories to first-class ship building craftsmen.

One device described herein, the simple laser, is cheap and can be productively applied. Low powered lasers are sufficient for most applications and with nominal precautions they do not impose any hazard. Welding arcs could be more dangerous to the passerby. The U. S. Department of Labor, in putting into effect the Occupation Safety and Health Act (OSHA), has established 1 milliwatt per square centimeter as the maximum permissible exposure of continuous laser radiation on the eye. All laser alignment techniques suggested herein necessarily conform to this stringent limit.

This manual first describes the creation of laser light, the laser beam, typical laser instruments used for alignment, and their accessories. At this point, some readers should envision for themselves, alignment applications, even new accessories, based on their own experience and needs. Thereafter, use of the laser beam for basic alignment functions are described. The next sections describe the applications of the foregoing to some typical shipbuilding alignment tasks. Appendices are included to provide useful information concerning safety, specifications for buying a laser, etc.

There are alignment techniques other than those suggested herein. Most presented are Representative of what is now being accomplished by optical means in the shipbuilding industry. It is reiterated that they are intentionally suggestive so that they can be applied in accordance with any detailed alignment procedure preferred by a shipyard.

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1.0 INTRODUCTION

1.1 LASER LIGHT

The name "laser" is formed from the initial letters in the term "light amplification by stimulated emission of radiation." It comes from a process like that used to generate ordinary fluorescent light. A fluorescent lamp features a mercury-vapor-filled glass tube, internally coated with a special powder. An electric arc within emits invisible ultraviolet light. This light energy is absorbed by the powder which then emits visible light. The lamp "fluoresces," i.e., its fine particle coating *emits radiation* in the form of visible *light* after being stimulated by radiation from another source.

Physicists explain this phenomenon using the generally known theory that an atom is like a planetary system in which its nucleus replaces the sun and its electrons replace the planets. They theorize further that, when an atom is stimulated it absorbs energy by widening its electron orbits. The flyball weights on a centrifugal governor behave this way. In both cases, when the stimulation is relieved, energy is released until the original energy levels are achieved. For an atom of a particular element, the energy difference is emitted as light radiation of a definite frequency, i.e., a specific wavelength or color. In a fluorescent lamp, the powder coating is compounded from atoms of different materials. These respond differently to the stimulation so that the increase and decrease processes take place randomly. The result of these various wavelengths, emitted without synchronization, is simulated daylight.

The laser uses like atoms having a slight margin of stability at a particular high energy level and a method of stimulation that can get most atoms "high" simultaneously. One "going off" will trigger all so that they emit synchronizing bursts of light at specific frequencies. Rapid repetitive bursts produce a steady light source with waves radiated in all directions. It is coherent, i.e., the waves of one frequency "move through space in "step" with one another. Its energy can be concentrated into a light beam that spreads out little over a long distance. It is this high intensity, almost parallel, light beam that is ideal for alignment. When created as visible light, it can be detected by placing any material, even clear glass, in its path. It can also be detected by electronic means.

1.2 LASER BEAM SOURCE

The laser beam source most commonly used for alignment (see Figure 1-1) features an envelope that contains gaseous elements and a means of stimulating them. (See also Appendix B.)

Special mirrors are incorporated that are:

- Designed to reflect selected light of one color
- Aligned to reflect only light waves that are parallel to the longitudinal axis
- Positioned to ensure that the reflected waves are in phase with the oncoming waves so that they reinforce each other, i.e., are amplified
- Silvered to achieve full reflection at one end and partial reflection at the other in order to permit the steady emergence of sufficiently amplified light waves.²

The laser light source is mounted in a rugged tubular housing, as illustrated in Figure 1-2, which:

- Provides means for maintaining the careful position and alignment of the mirrors
- Incorporates an optical system that further concentrates or “collimates” the diverging rays to form a more parallel light beam.³
- Protects the internals and provides a cylinder that, if finished to National Aircraft Standards (NAS)⁴ specifications, would be interchangeable with the accessories for conventional optical telescopes used for alignment.

Often the mixture is of helium and neon. Stimulation can be started with an electric arc and sustained by applying radio-frequency voltage. This energizes the helium atoms that, during collisions, transfer energy to the neon atoms. The latter have the needed “slight margin of stability” necessary for producing laser light.

² “pulsed” laser is designed to prevent the steady emergence of light in order to create a very high energy buildup internally. Special “pulse” techniques release energy that is concentrated enough for burning and welding applications. It is this type of laser that is extremely hazardous.

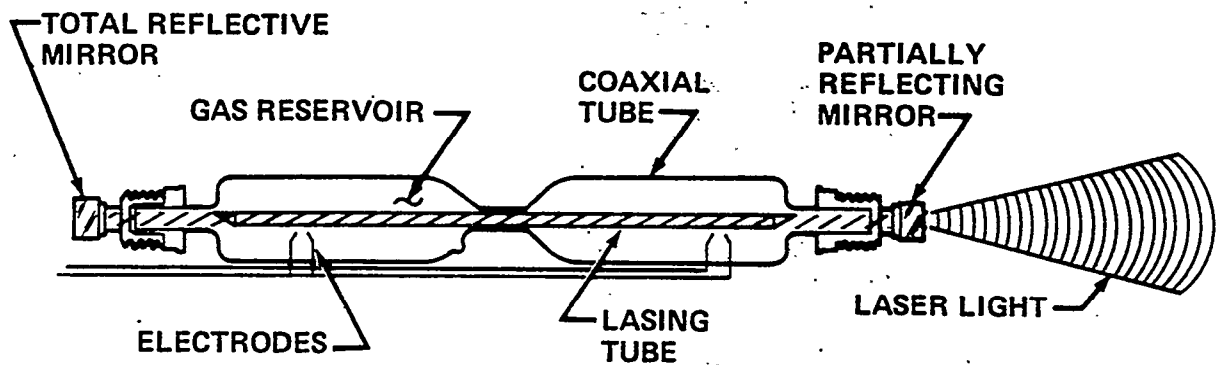


Figure 1-1: Laser Beam Source

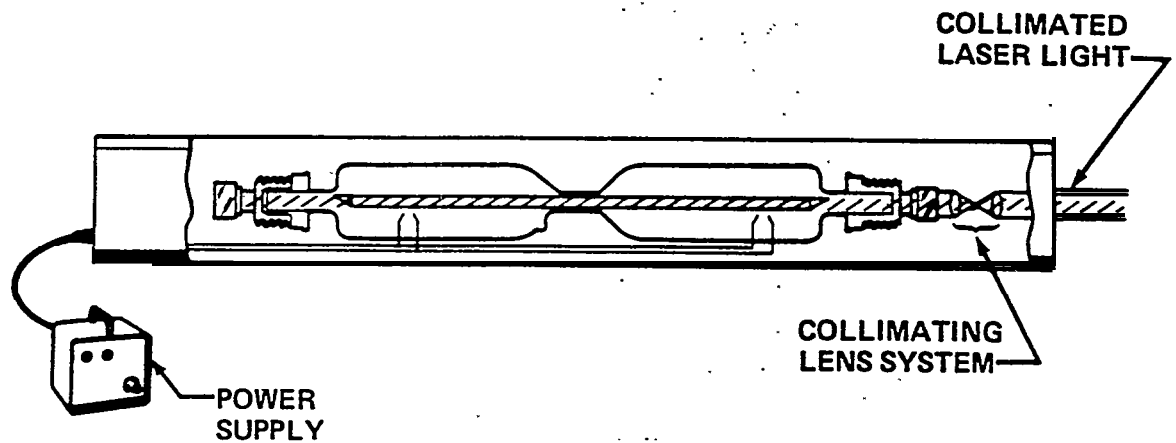


Figure 1-2: Collimated Laser Beam Source

³Light waves bend or diffract around the edges of an object in much the same way that water waves bend around corners. Thus, after passing the edges of an orifice, they spread. They are returned to near parallelism by modifying the shape of the partially reflective mirror and by adding collimating lenses as shown in Figure 1-2. Limitations in the manufacture of optical components and additional diffraction due to passage through the atmosphere, prevent obtaining a perfectly collimated light beam.

⁴The National Aerospace Standards (NAS) are specifications written by the Aerospace Industries Association (AIA) of America, Inc., 1725 De Sales St. N.W., Washington, D.C.

1.3 APPLYING LASERS⁵ FOR ALIGNMENT

As with all technologies, there is no one tool, no one measuring instrument that will satisfy all production requirements for shipbuilding. We need micrometers for precise measurement of small items. We need the 6-inch scale for measuring hand-sized parts, and we need measuring tapes for measuring large sections. Similarly, one specific laser device cannot efficiently cover the full spectrum of alignment requirements in shipbuilding.

Terminology for laser beam sources used for alignment varies between users and between vendors. To eliminate confusion, the following, purposely concise, definitions apply throughout this manual (see also the Glossary):

- 1 The alignment laser is analogous to the alignment telescope, Figure 1-3. Its beam is precisely centered relative to its NAS finished cylindrical surfaces. The mechanical and optical axes of the beam's origin coincide.

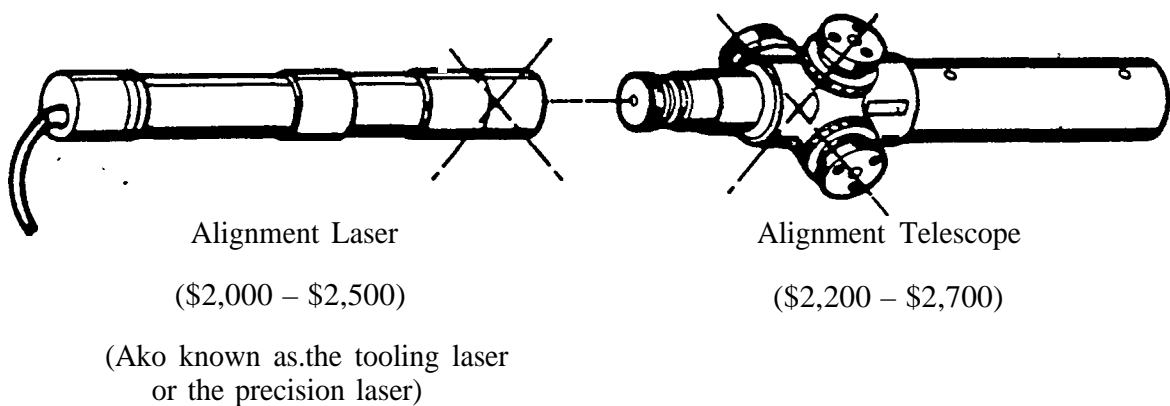


Figure I-3: Comparison of Alignment Laser and Alignment Telescope

⁵"Laser," the acronym for "light amplification by stimulated emission of radiation: which applies to the light, is also in general use for designating the device that produces the light.

The transit laser is analogous to the transit telescope, Figure 1-4. Its beam is precisely aligned relative to the viewing axis of the telescope upon which it is mounted. A model fitted with transfer optics will project the laser beam coincident with the optical axis, Figure 1-5. However, its beam diameter and degree of collimation for a specific range is dependent upon the telescope's lens system and focusing capabilities. Its beam is collimated only when the telescope is focused at infinity. It can be focused to a very small spot at other ranges.

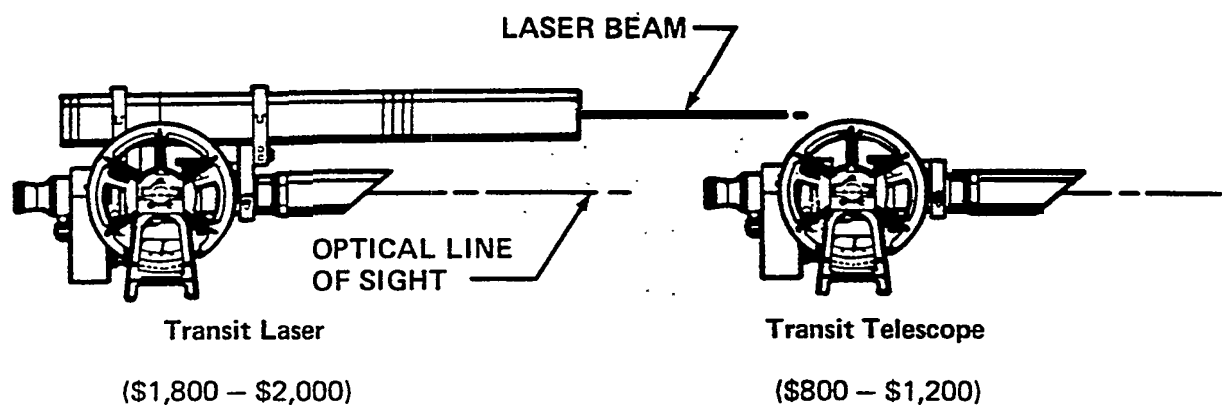


Figure 1-4: Comparison of Transit Laser and Surveyor's Transit Telescope

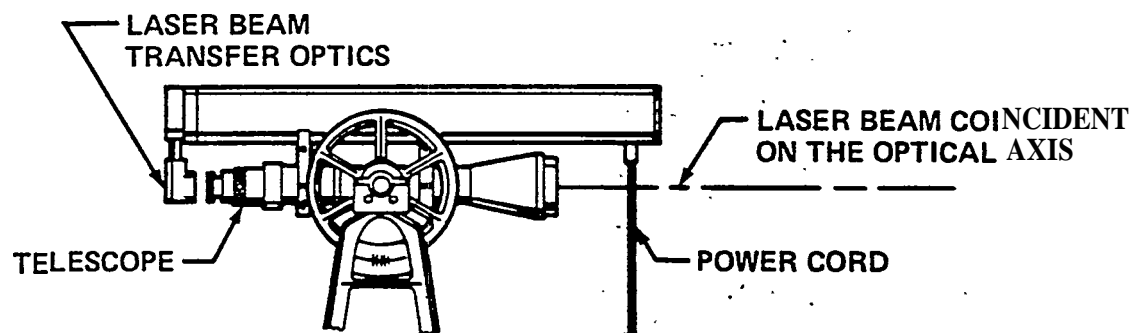


Figure 1-5: Transit Laser With Laser Beam and Telescope Optics Coincident

- The laser level is analogous to the surveyor's level, Figure I-6. Its beam is precisely aligned relative to a spirit-level vial.

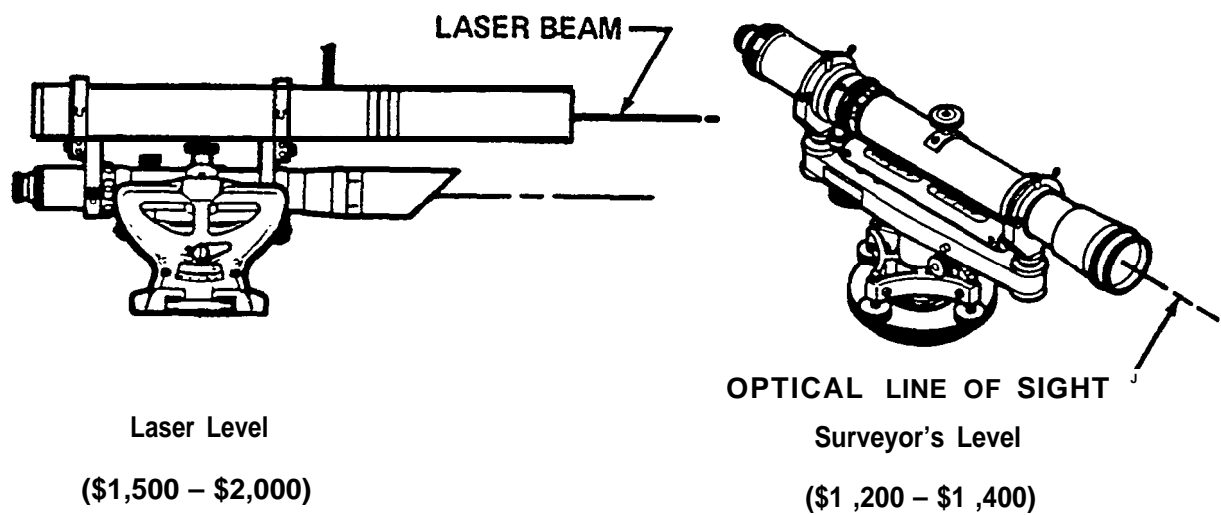


Figure I-6: Laser Level Compared With Surveyor's Level

- The laser is analogous to the simple telescope. Figure 1-7. Its beam is not aligned to any reference. The laser housing may be rectangular, Figure 1-8.

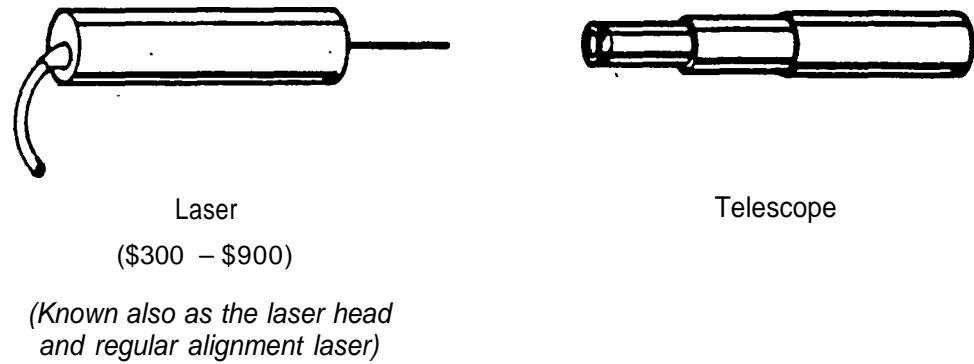


Figure 1-7: Simple Laser Compared with Simple Telescope

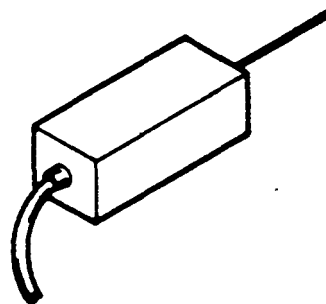


Figure 1-8: Rectangular Laser Housing

2.0 ACCESSORIES AND THEIR FUNCTIONS

Many accessories that are used for laser devices are the same as those used for optical devices, and they now exist in most shipyards.

2.1 ACCESSORIES FOR ALIGNMENT LASER

2.1.1 Spherical Adapter

The spherical adapter (Figure 2-1) is manufactured to NAS specifications and is used to establish a spherical reference of known radius around the point where the mechanical and optical axes of the beam's origin coincide, Figure 2-2. It is also used to establish the same spherical reference around the center of a visual target or an electronic centering target. Precision measurements can be made from the surface of the spherical adapter.

Spherical adapters with a locking collet can be purchased. The purpose of the locking collet is to firmly secure the adapter to the alignment laser.

The spherical adapter may be used with a shipyard-manufactured jig (Figure 2-3), but more often it is used in conjunction with the adjustable-cup mount.

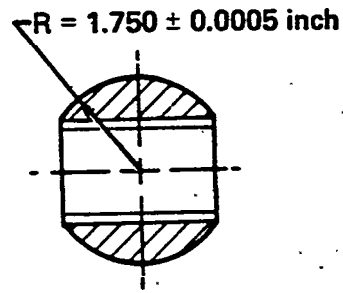


Figure 2-1: Spherical Adapter

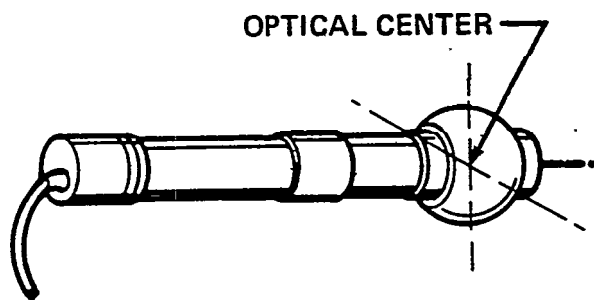


Figure 2-2: Alignment Laser With Spherical Adapter Attached

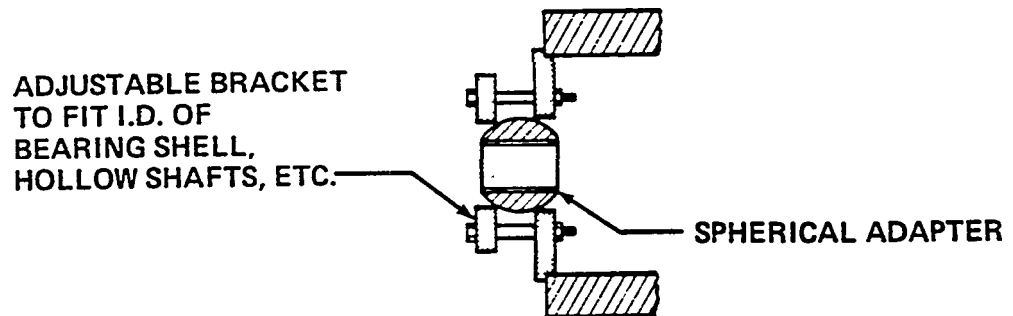
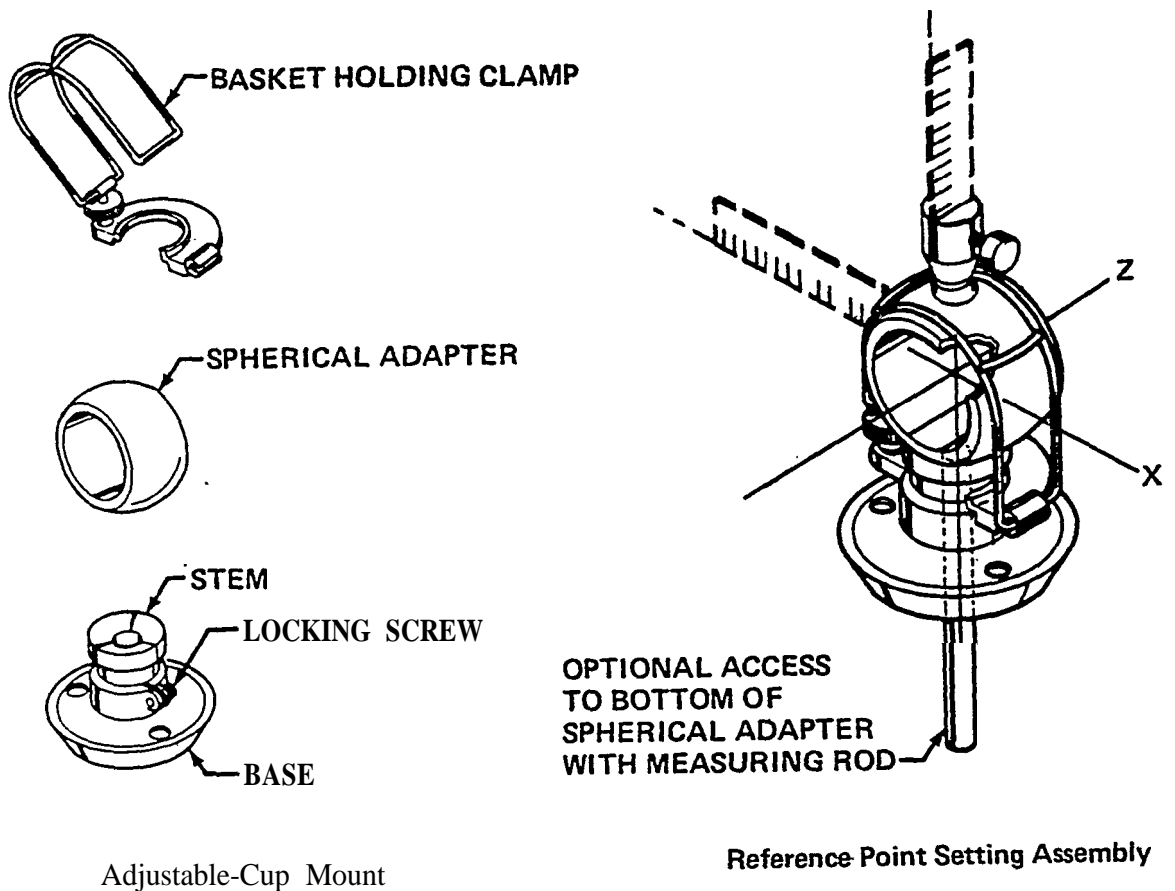


Figure 2-3: Shipyard-Manufactured Jig for Spherical Adapter

2.1.2 Adjustable-Cup Mount

The adjustable-cup mount (Figure 2-4) facilitates positioning the spherical adapter in any orientation around a permanent reference point. For high accuracy, its base is doweled in addition to being bolted to the structure upon which it is attached. In other applications, it could be attached with C-clamps. It is adjustable in one axis over a range of 2-1/2 inches. When its stem is adjusted and locked, the spherical adapter and other attachments may be removed and replaced repetitively without disturbing the reference point. Sights or measurements may be made through the hollow adjustable stem.



Adjustable-Cup Mount

Reference Point Setting Assembly

Figure 2-4: Adjustable-Cup Mount and Reference Point Setting Assembly

2.1.3 Holding Clamp

The holding clamp firmly anchors the spherical adapter to the adjustable-cup mount (Figure 24) and is designed to allow maximum access to the sphere's surface for measurement purposes.

2.1.4 Reference Point Setting Assembly

The reference point setting assembly (Figure 2-4) is used to deliberately fix a reference point. Precision measurements can be made by measuring to the surface of the spherical adapter because its center is coincident with the reference point. Once a reference point is set with the assembly, the spherical adapter can be rotated without disturbing the reference point, Figure 2-5.

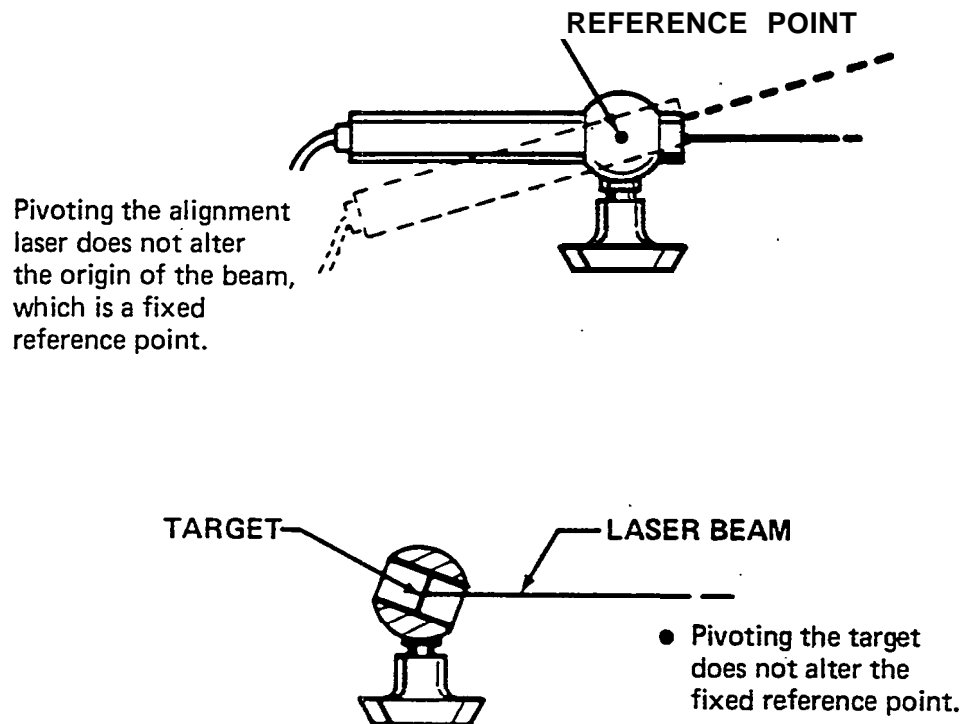


Figure 2-5: Rotating Spherical Adapter Does Not Disturb Reference Point

2.1.5 Standard Alignment Bracket

The standard alignment bracket is used with a permanently positioned adjustable-cup mount, Figure 2-6. It grasps the alignment laser to prevent axial and rotational movement. It is provided with precision adjusting screws for rotational adjustment about the reference point within the spherical adapter.

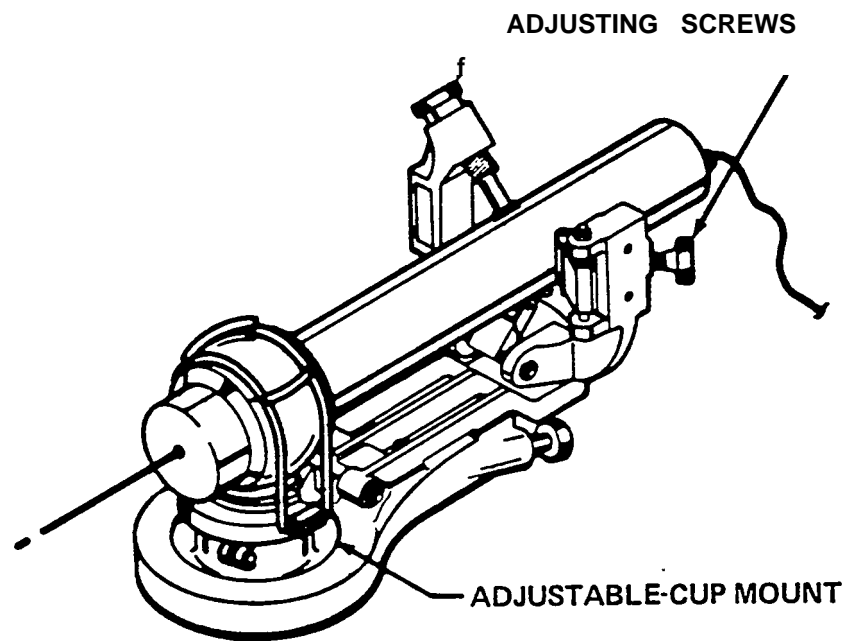


Figure 2-6: Holding Bracket for Alignment Laser

Variations of the standard alignment bracket can be easily manufactured in the shipyard, Figure 2-7. Selection of a specific bracket is dependent upon a particular alignment application.

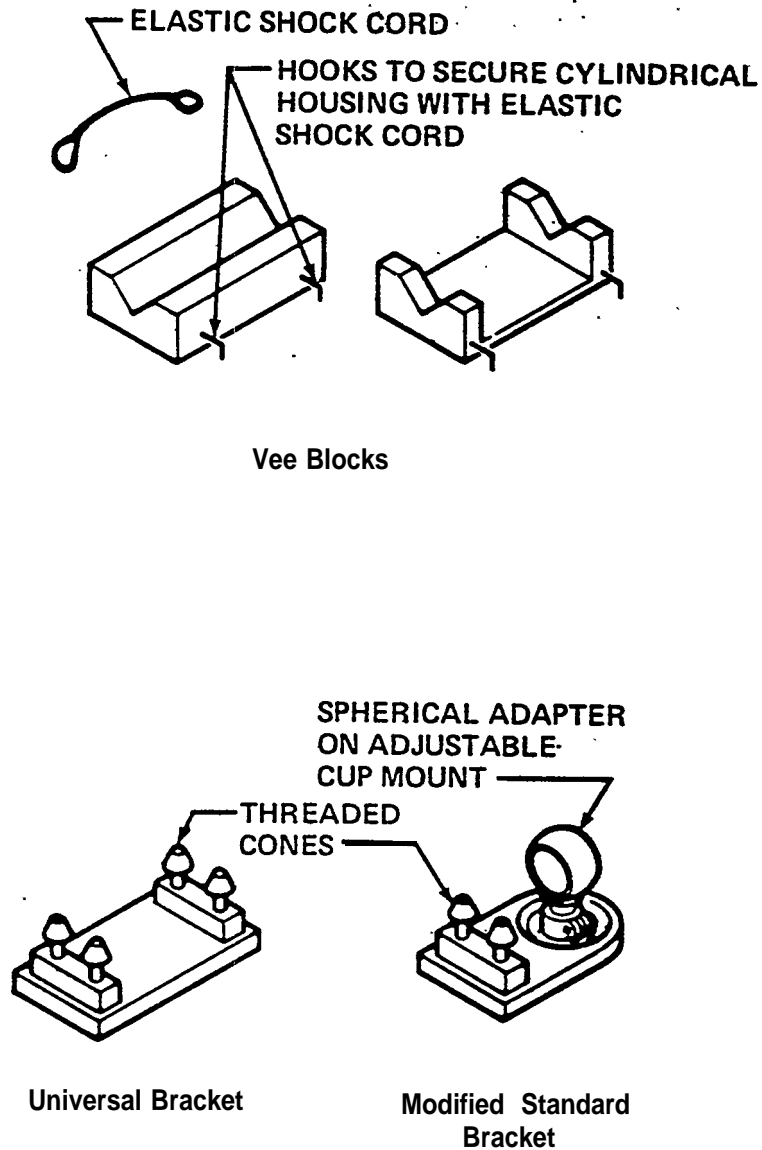


Figure 2-7: Shipyard-Manufactured Laser Brackets

2.1.6 Adjustable Target Holder [Spider]

The adjustable target is a type of bracket (Figure 2-8) designed to support and facilitate adjustment of a target within the center of a cylinder. Some are fitted with attached inside micrometers or dial indicators that facilitate centering. Normally, they are available as a single kit useful for 16- to 68-inch diameters.

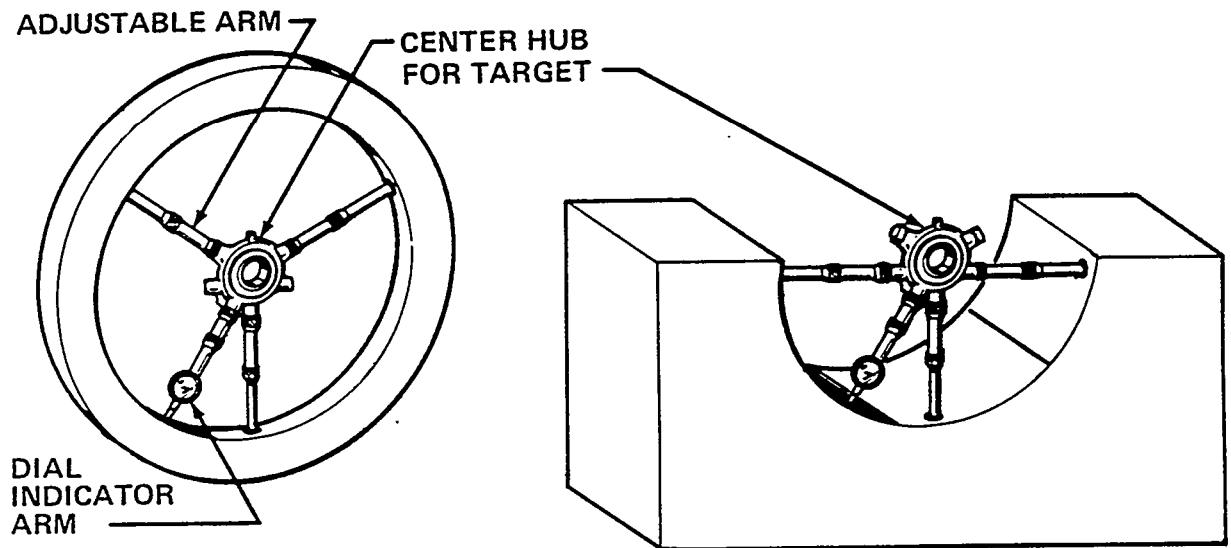


Figure 2-8: Adjustable Target Holder

2.1.7 Vertical Holding Bracket

The vertical holding bracket is equipped with spirit levels and adjusting screws that facilitate projecting the laser beam vertically, Figure 2-9.

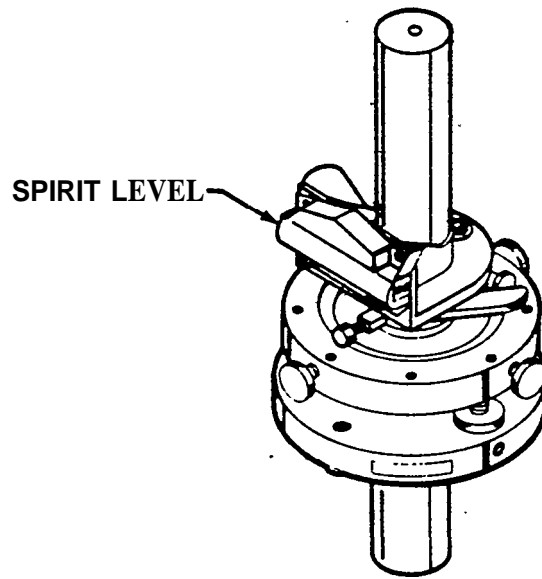


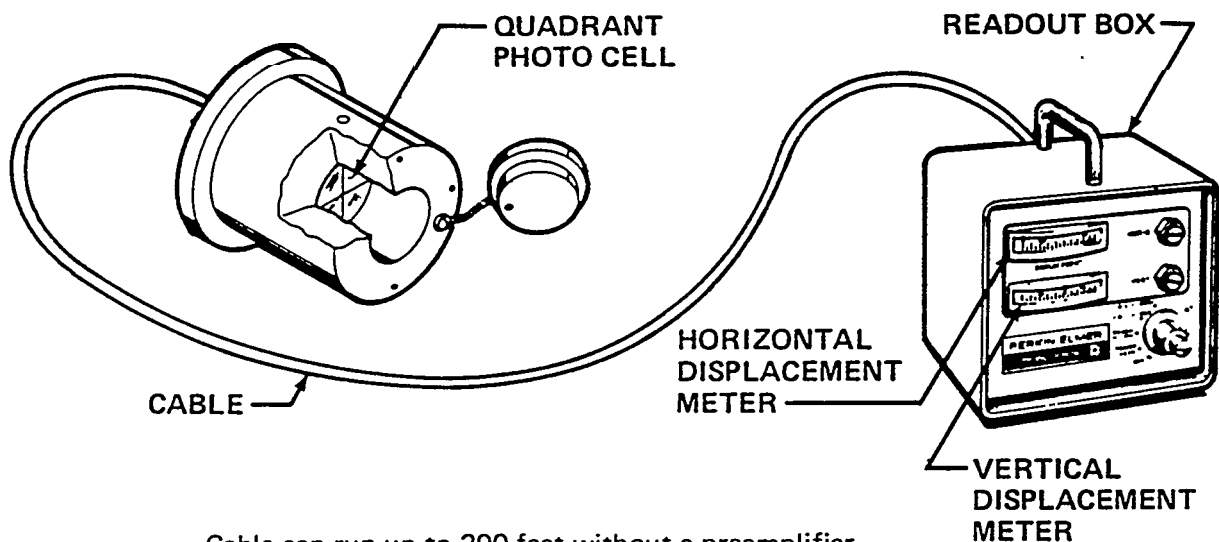
Figure 2-9: Vertical Holding Bracket for Alignment Laser

2.1.8 Electronic Centering Detector (Electronic Target)

This detector consists of a disc-shaped light-sensitive photo cell that is divided into four equal parts. The voltages generated by the quadrant cells when struck-by laser light are compared in a readout box equipped with meters. indicating horizontal and vertical displacement, Figure 2-10. The enclosed circuitry operates on the null principle, i.e., when the laser beam falls equally on each quadrant cell of diagonally opposite pairs, equal and opposing voltages are generated. There is no subsequent current flow: the appropriate meter will remain at zero indicating true center. When the laser beam is off center, the opposing voltages will be unequal causing a current flow that can be read on a calibrated meter in any convenient increment of lineal measure, Figure 2-11.

Normally, electronic centering detector systems are provided as part of a precision alignment kit that includes an alignment laser and at least two matched electronic targets and a readout box. Generally, all components should be purchased from the same manufacturer. Accuracies as fine as 0.0001 inch are possible. Even with the greater tolerances allowed in shipbuilding, there should be assurance that the electronic targets are matched with a specific alignment laser.

The housing of the electronic centering detector is dimensioned in accordance with NAS specifications. It is provided with a flange that ensures precise location of the light-sensitive surface at the center of a spherical adapter, Figure 2-12.



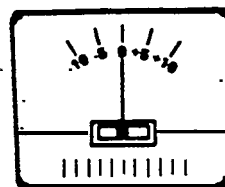
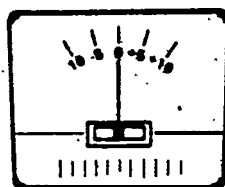
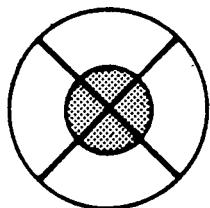
Cable can run up to 200 feet without a preamplifier.
Shipyard can manufacture cable with No. 18 AWG,
three-conductor shielded wire.

Figure 2-10: Electronic Centering Detector and Readout Box

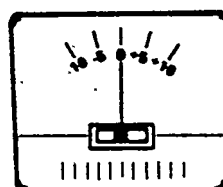
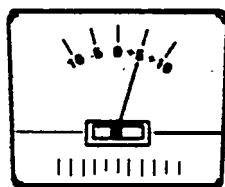
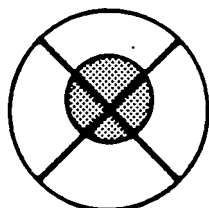
Laser beam position

Vertical meter

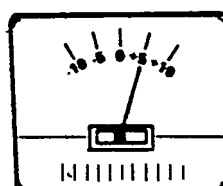
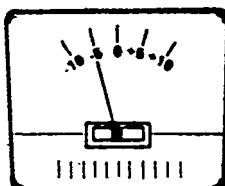
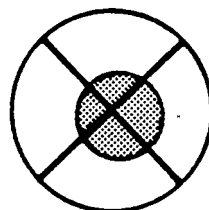
Horizontal meter



Laser Beam Centered on Detector



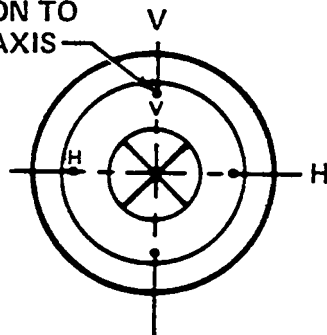
Laser Beam Displaced Upward



Laser Beam Down and to Right

Figure 2-11: Readout Box Display of Laser Beam

MARKED FOR
ORIENTATION TO
PRINCIPAL AXIS



LIGHT-SENSITIVE
SURFACE

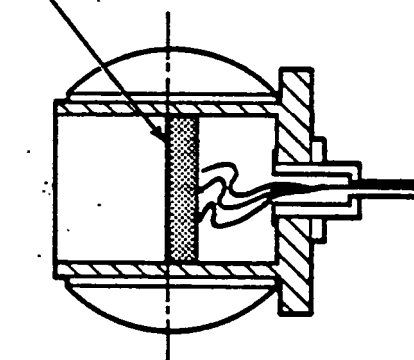


Figure 2-12: Electronic Detector Mounted in Spherical Adapter

2.1.9 See-Through Detector

The see-through detector (Figure 2-13) is an electronic target that uses a beam splitter to divert some light energy for sensing while permitting the remainder to continue. There should be assurance that they are matched with a specific alignment laser.

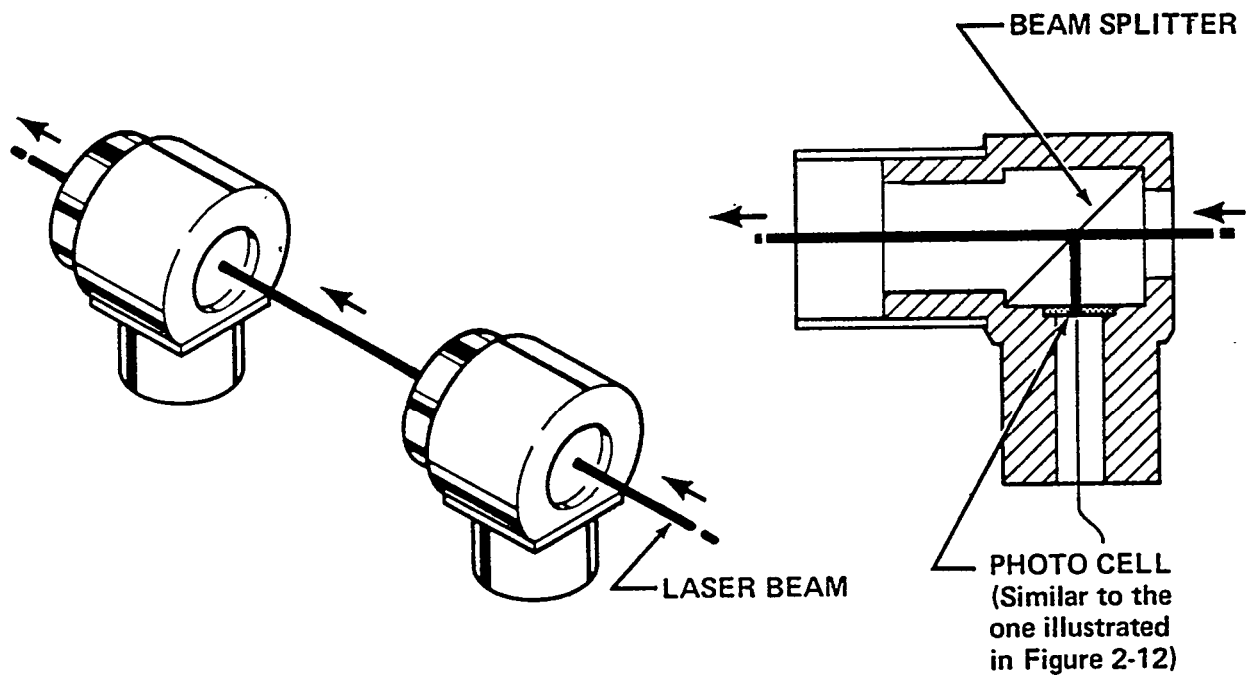


Figure 2-13: See -Through Electronic Detector

2.1.10 Single-Axis Electronic Detector (Wand)

The single-axis electronic detector (Figure 2-14) employs a split photo cell, a microammeter, and a null circuit. When the microammeter reads zero, i.e., at null, the laser beam is evenly divided on each half of the photo cell. When in this condition, the measurement is read directly off the attached measuring device.

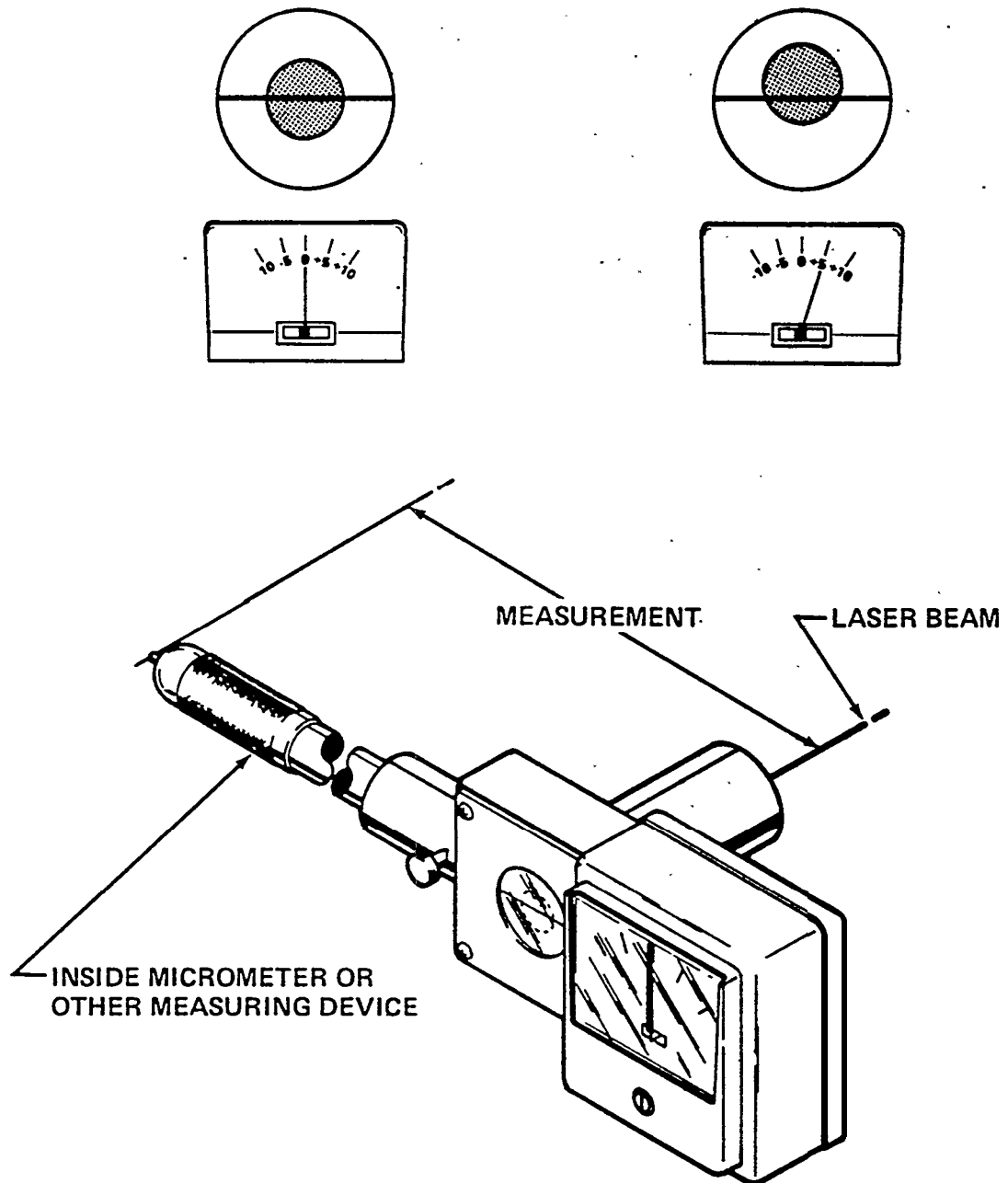


Figure 2-14: Single-Axis Detector

2.1.11 Visual Targets

Visual targets (Figure 2-15) are cheap to make and can be easily manufactured in a shipyard. Accuracies better than 1/32 inch or 1 millimeter can readily be achieved if the targets are shielded from bright light and if each target hole diameter is matched to the beam diameter at a specific location.

Transparent and translucent materials are best because, when properly shaped, they scatter or diffuse intercepted laser light. (See Appendix C for manufacturing details.)

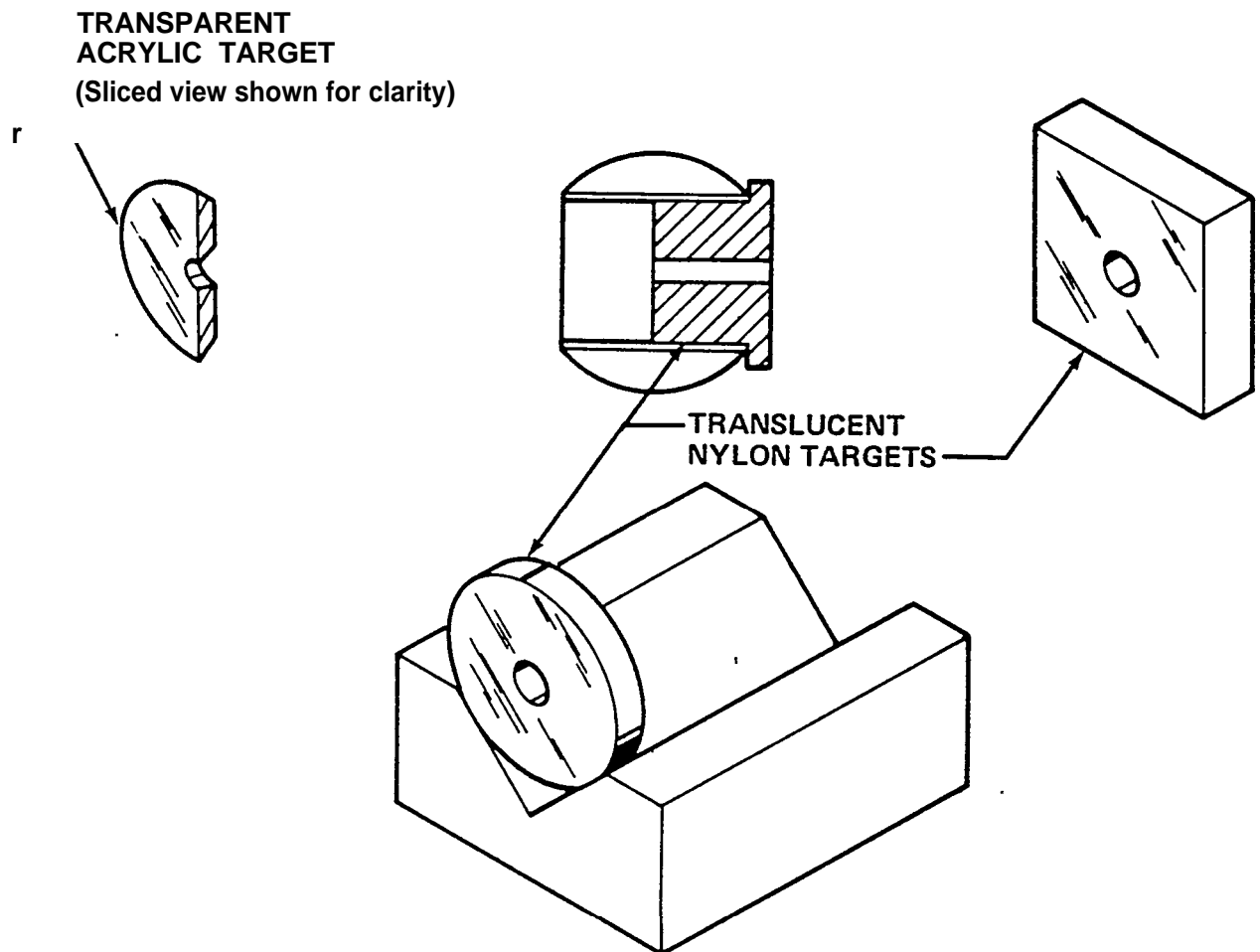


Figure 2-15: Visual Targets

2.1.12 Autoreflecting Head

The autoreflecting head (Figure 2-16) attaches to the alignment laser used as the beam source. It is primarily for detecting the center of the same beam when it is reflected back from a mirror. Centering with the autoreflecting head ensures that the returning beam is coincident with the exiting beam and that both are perpendicular to the mirror's surface.

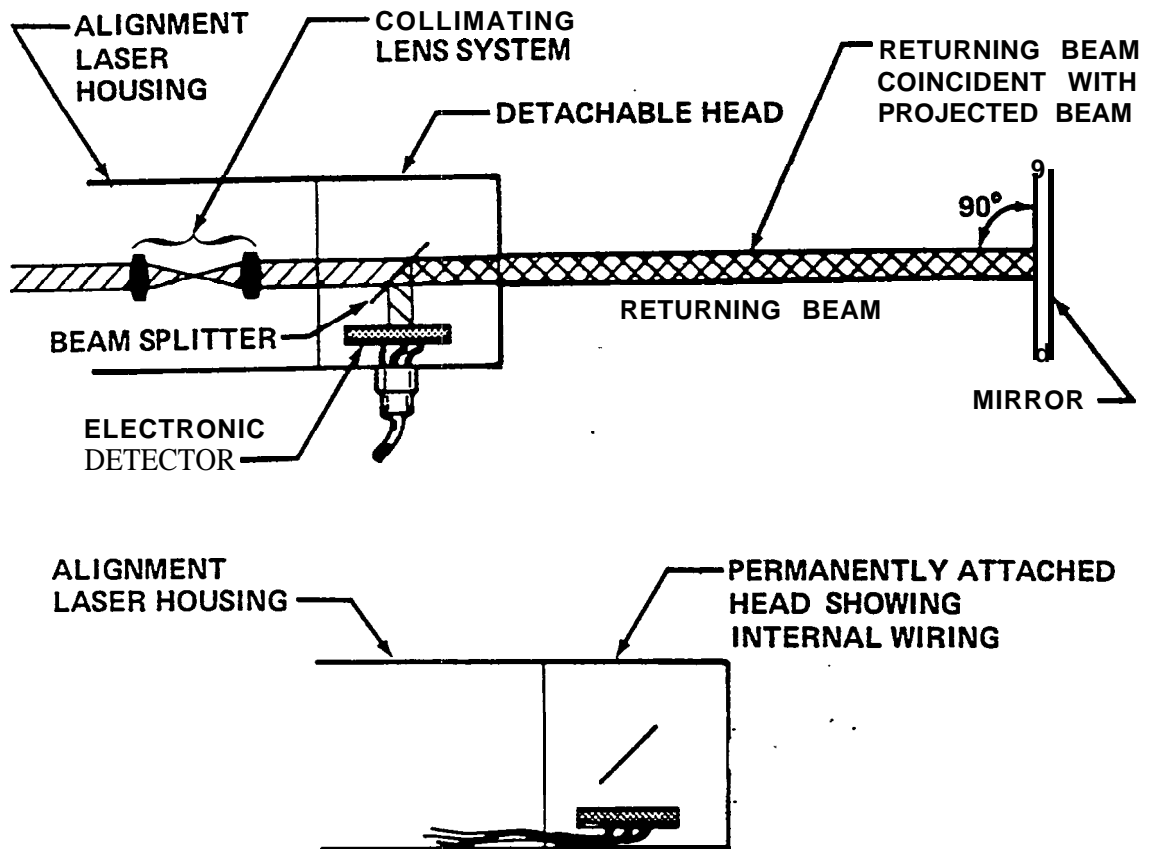
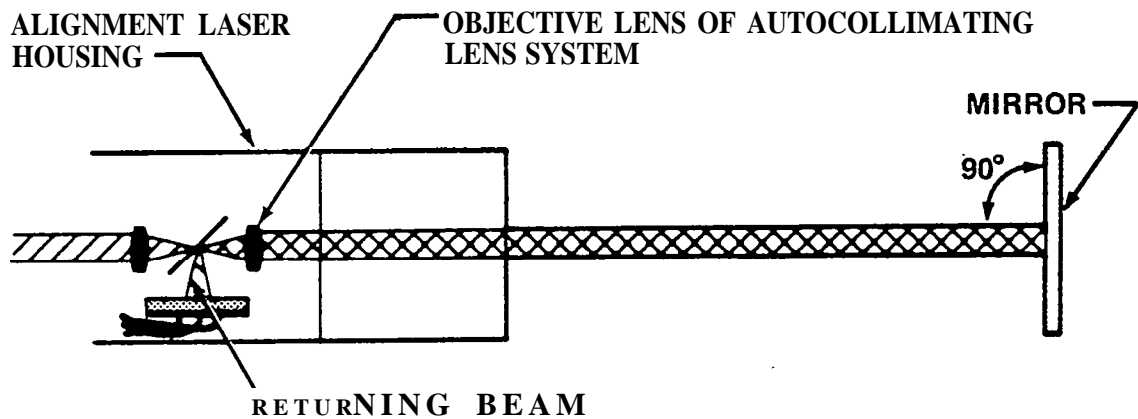


Figure 2-16: Alignment Laser Autoreflecting Head

2.1.13 Autocollimating Head

The autocollimating head (Figure 2-17) is a built-in feature that serves the same purposes as the autoreflecting head except that it is more accurate when the beam source and mirror are less than 10 feet or 3 meters apart. It has an additional capability for measuring small angles.



- The electronic target is positioned to intercept the returning beam at a distance equivalent to the focal length of the objective lens.

Figure 2- I 7: Alignment Laser Auto collimating Head

2.1.14 Vertical-Hanging Leveling Mirror

This mirror is a precision mirror delicately balanced and suspended so that it is in a true vertical plane. A beam made perpendicular to it, as by autoreflection or autocollimation, will be level, Figure 2-18.

The vertical-hanging leveling mirror may also be used to redirect a laser beam in any direction about a level reference, Figure 2-19.

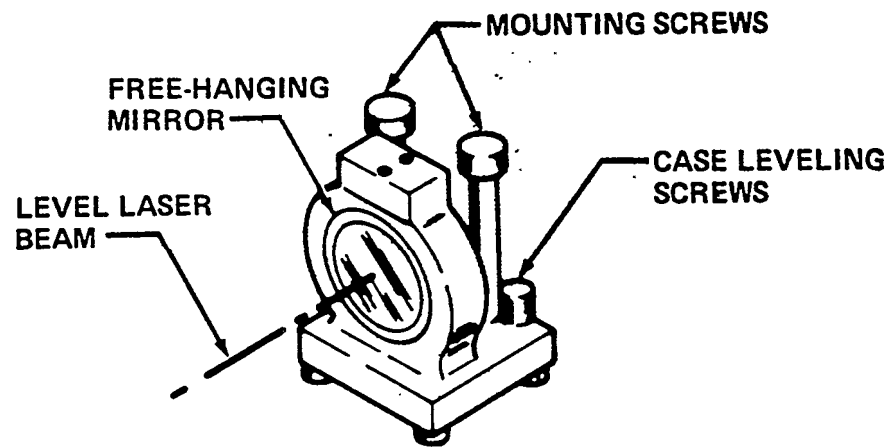


Figure 2-18: Vertical-Hanging Leveling Mirror

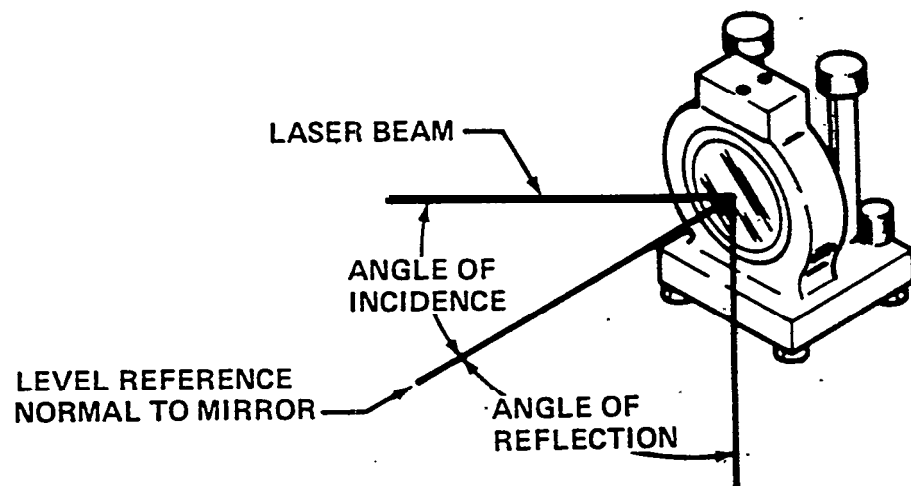


Figure 2-19: Redirecting Laser Beam Using Vertical-Hanging Mirror

2.1.15 First-Surface Precision Mirror

The first-surface precision mirror (Figure 2-20) is fitted with a magnetic, spindle, or other types of mounting adapters that establish it as parallel to a reference plane or perpendicular to a reference axis. Some are fitted with adjusting screws so that they may be skewed.

A beam can be made perpendicular to a mirror surface by autoreflection or autocollimation. A mirror can be used to redirect a laser beam about a line perpendicular to its surface.

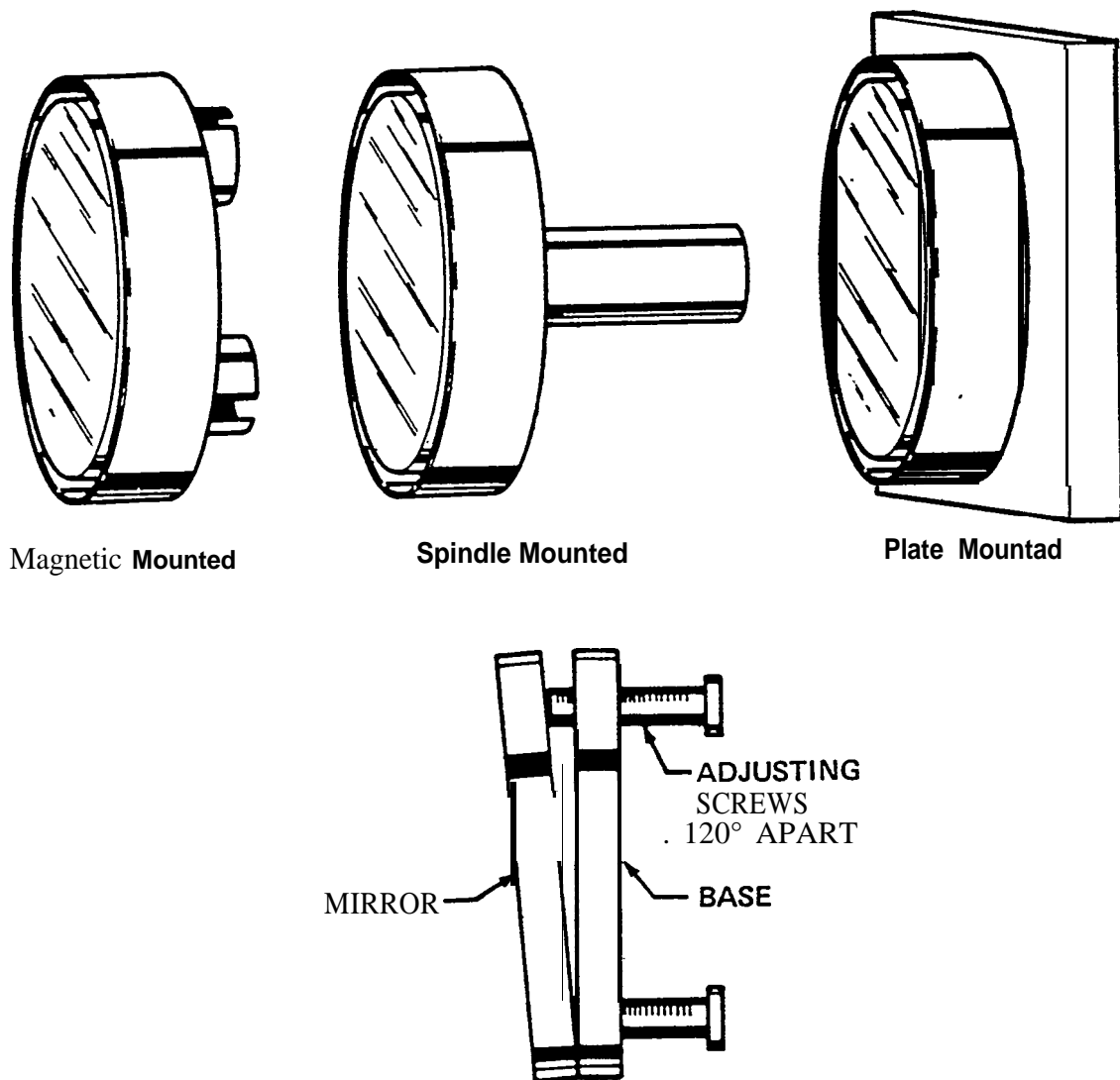


Figure 2-20: First-Surface Precision Mirror

2.1.116 Optical Square

The optical square (Figure 2-21) is attached to the alignment laser and is used to establish a beam perpendicular to a reference beam. The optical square is available in varied configurations. However, they are all equipped with a sphere that is ground to NAS specifications. The sphere can be mounted on the adjustable-cup mount.

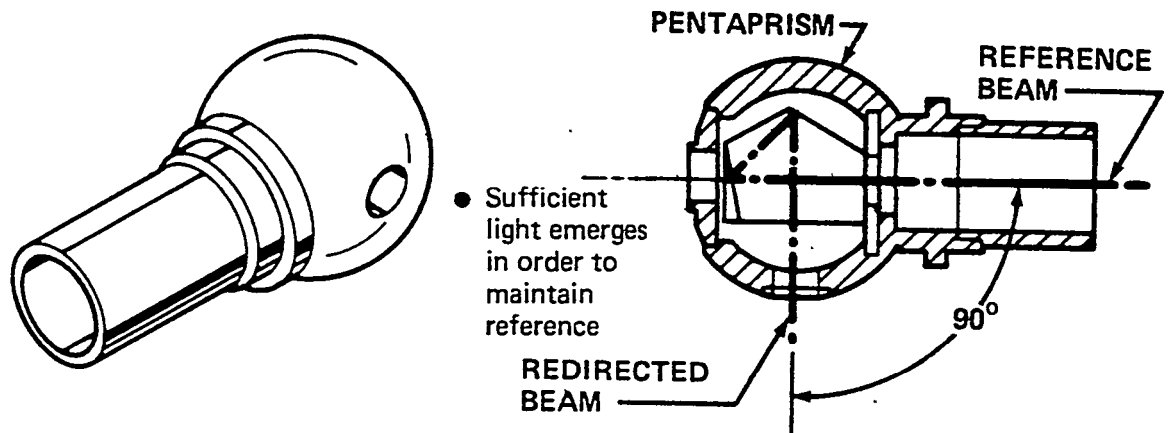


Figure 2-21: Optical Square

2.1.17 Planing Prism

The planing prism is a very precise device. It generates planes by rotation of a prism, Figure 2-22. The axis about which the prism rotates must be precisely adjusted perpendicular to the laser beam before use. This limits its application to beam sources that have an autoreflecting or autocollimating capability.

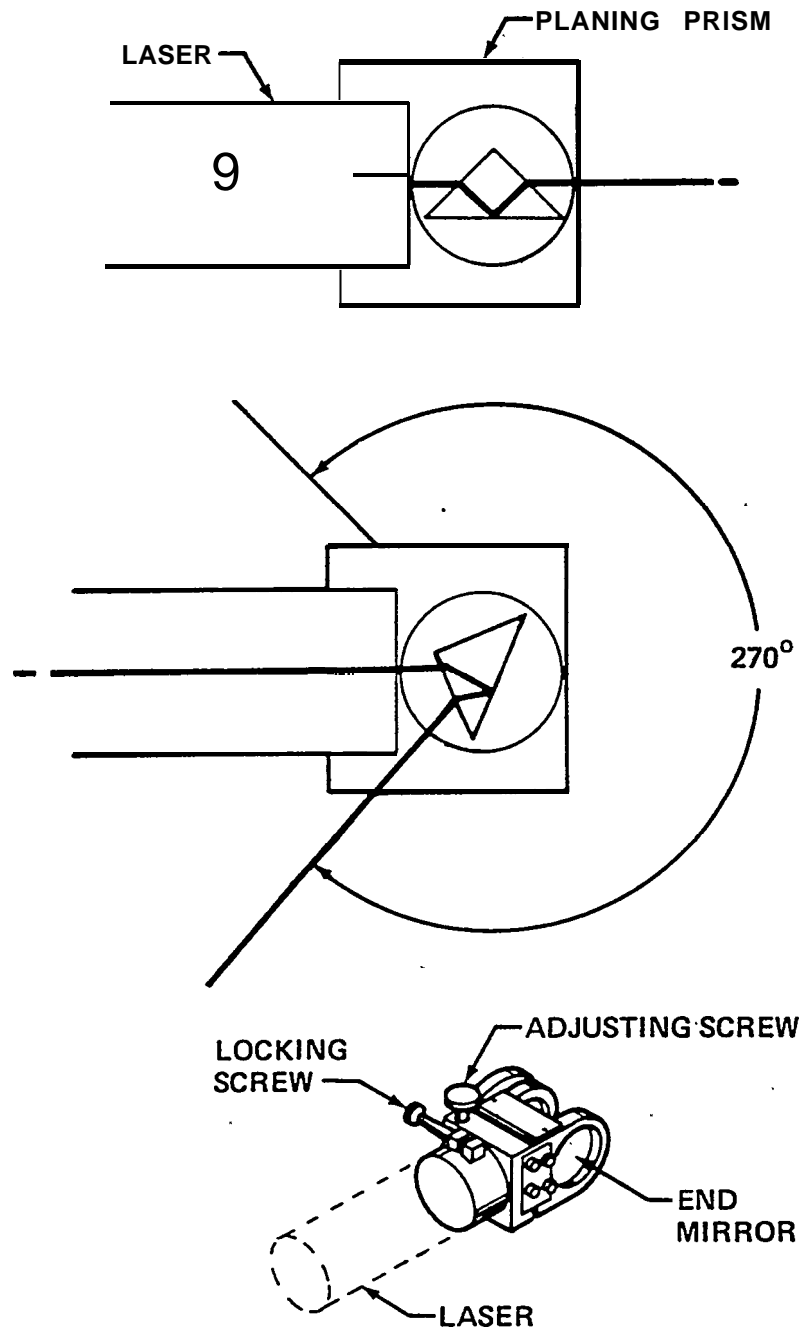


Figure 2-22: Planing Prism

The planing prism is equipped with an end mirror necessary for orienting the plane to be generated perpendicular to a reference beam, Figure 2-23. Necessarily, the reference beam source must also have an autoreflecting or autocollimating capability.

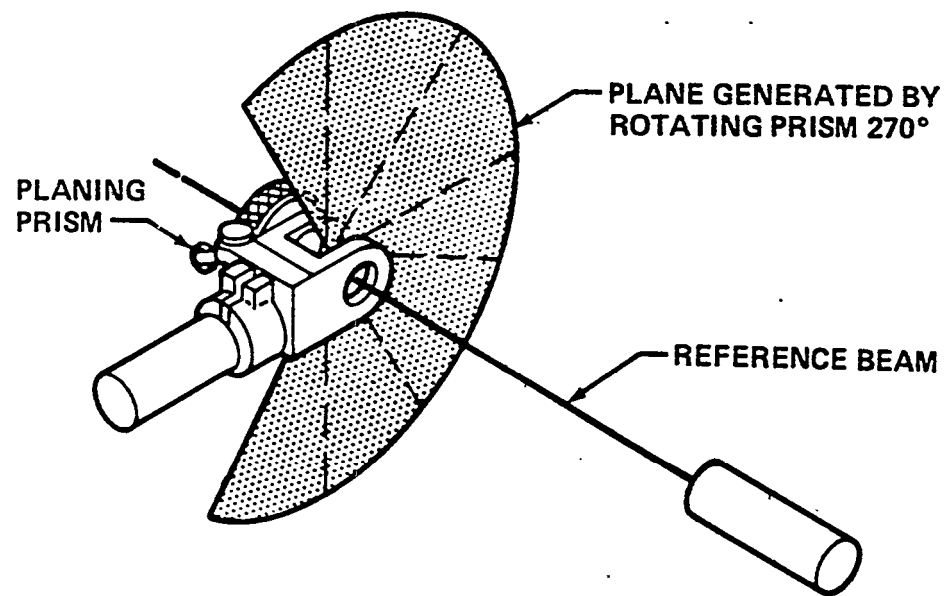


Figure 2-23: Autocollimating to the Planing Prism

2.1.18 Planing Penta Prism

The planing penta prism is used to generate planes perpendicular to a remotely located laser beam source. It is a precisely manufactured device that functions by rotation of a prism in precision bearings, Figure 2-24. The axis about which the prism rotates must have the beam aligned to the center of the entrance and exit orifices to ensure perpendicularity. For the greatest accuracy, it should be aligned with an autocollimating laser source.

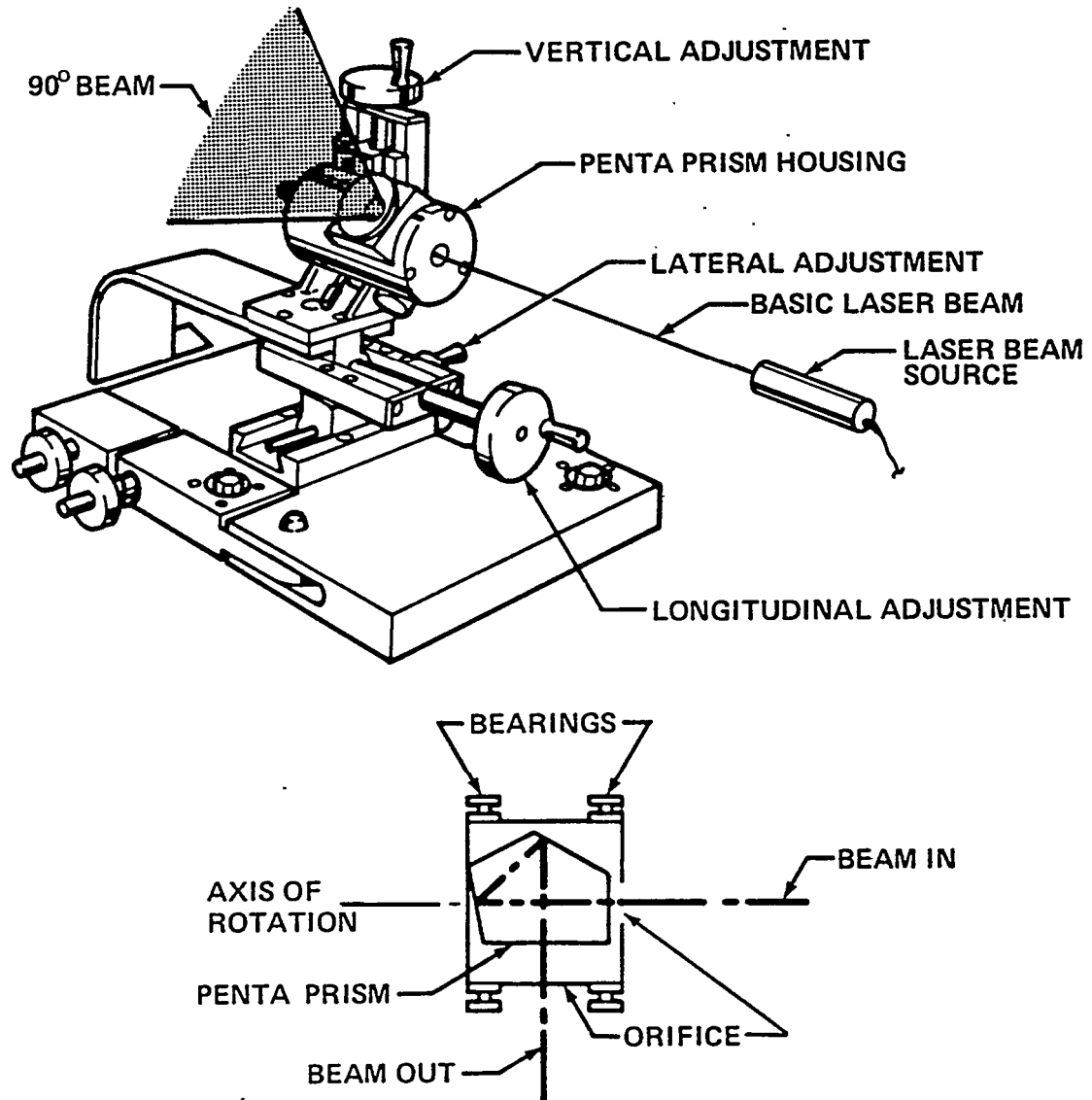


Figure 2-24: Planing Penta Prism

2.1.19 Mounting Bases

The adjustable-cup mount and holding brackets of various types may be mounted on any convenient flat surface or a stand manufactured by a shipyard, Figure 2-25. A 6-inch-square steel plate would suffice for holding the adjustable-cup mount. Adequate clearances must be allowed for the other attachments.

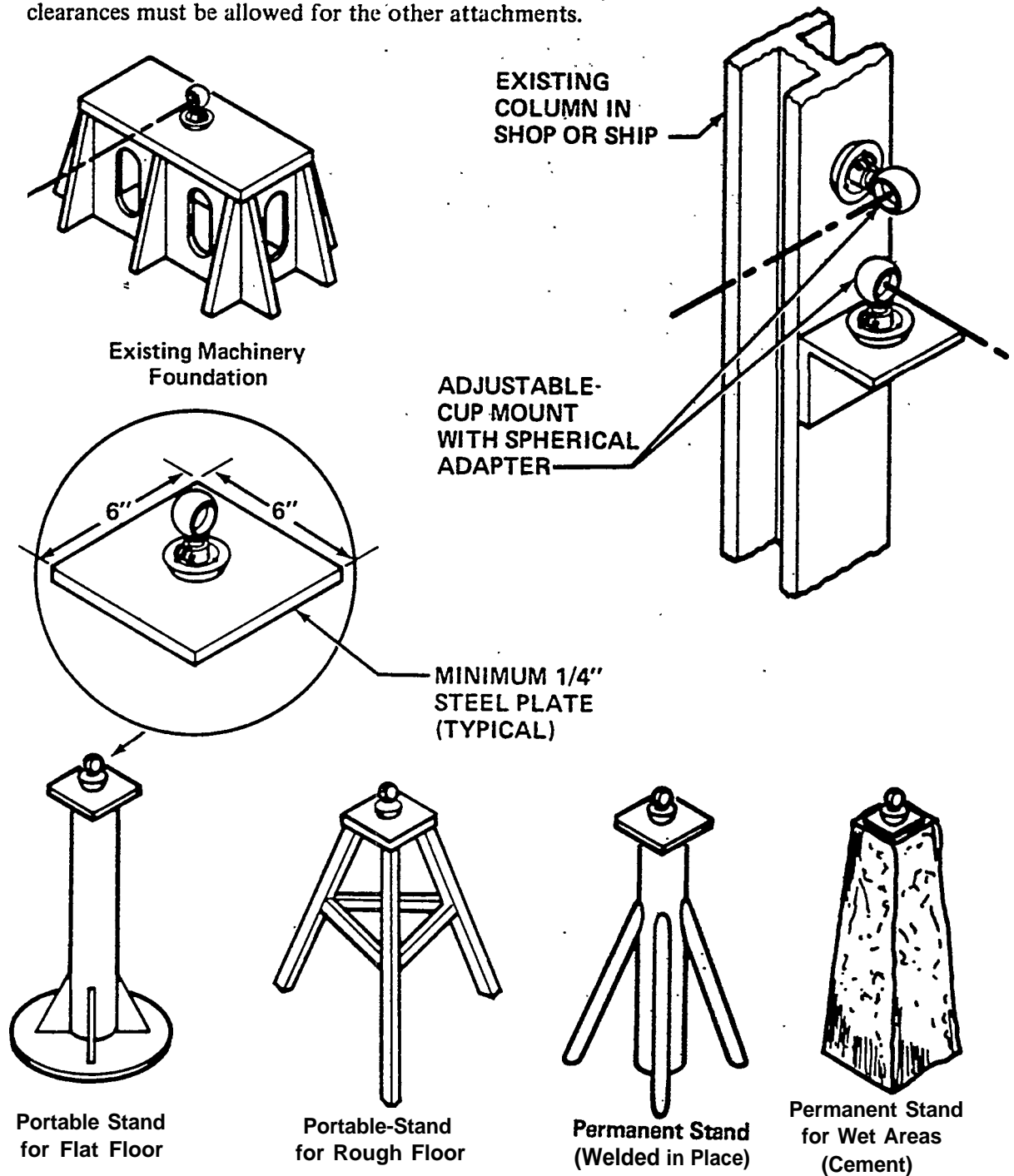


Figure 2-25: Mounting Bases

2.2 ACCESSORIES FOR TRANSIT LASER

2.2.1 Calibration Target

The calibration target (Figure 2-26) is peculiar to that transit laser designed to have its laser beam parallel to its optical line of sight. The calibration target is the device used to ensure that the laser beam and optical line of sight are parallel.

2.2.2 Fan-Beam Lens

The fan-beam lens (Figure 2-27) focuses the single-line beam into a thin fan-shaped beam. Because its energy is dispersed throughout the fan, it must be used in subdued light and at relatively short ranges.

2.2.3 Applying Alignment Laser Accessories

Alignment laser accessories that can be used with the transit laser are:

- Reference point setting assembly (Figure 2-4), for holding a target only .
- Adjustable target holder (Figure 2-8)
- Electronic centering detector—electronic target (Figure 2-1 O)—provided there is assurance that the electronic targets are matched with the laser
- See-through detector (Figure 2-1 3); provided that they are matched with the laser
- Single-axis electronic detector—wand (Figure 2-1 4)
- Visual targets (Figure 2-15), supplemented by those illustrated in Figure 2-28
- Vertical-hanging leveling mirror (Figures 2-17 and 2-19)
- First-surface precision mirror (Figure 2-20)
- Planing penta prism (Figure 2-24)
- Mounting bases (Figure 2-25), provided adapters are employed, Figure 2-29.

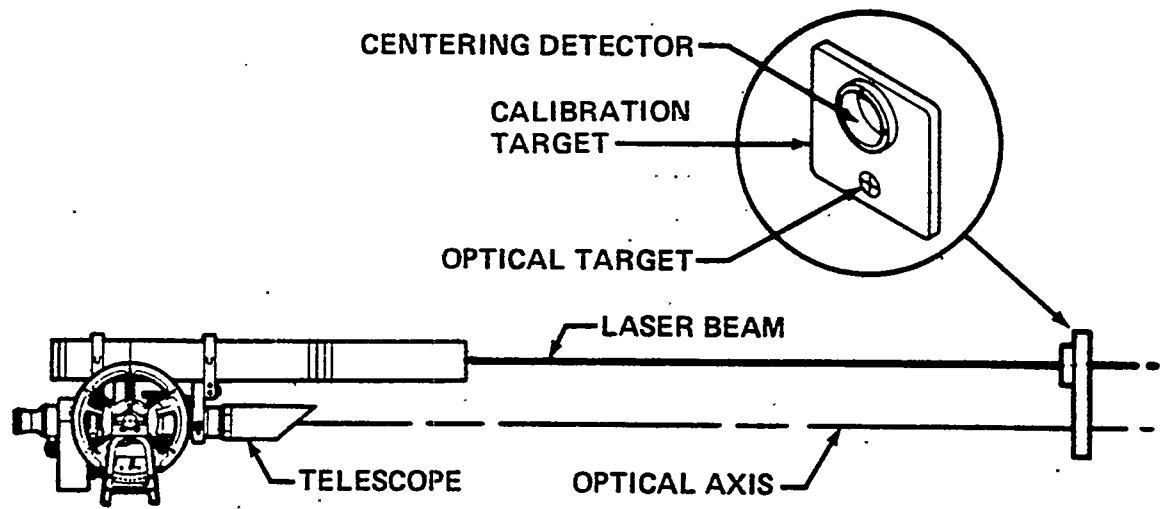


Figure 2-26: Calibration Target

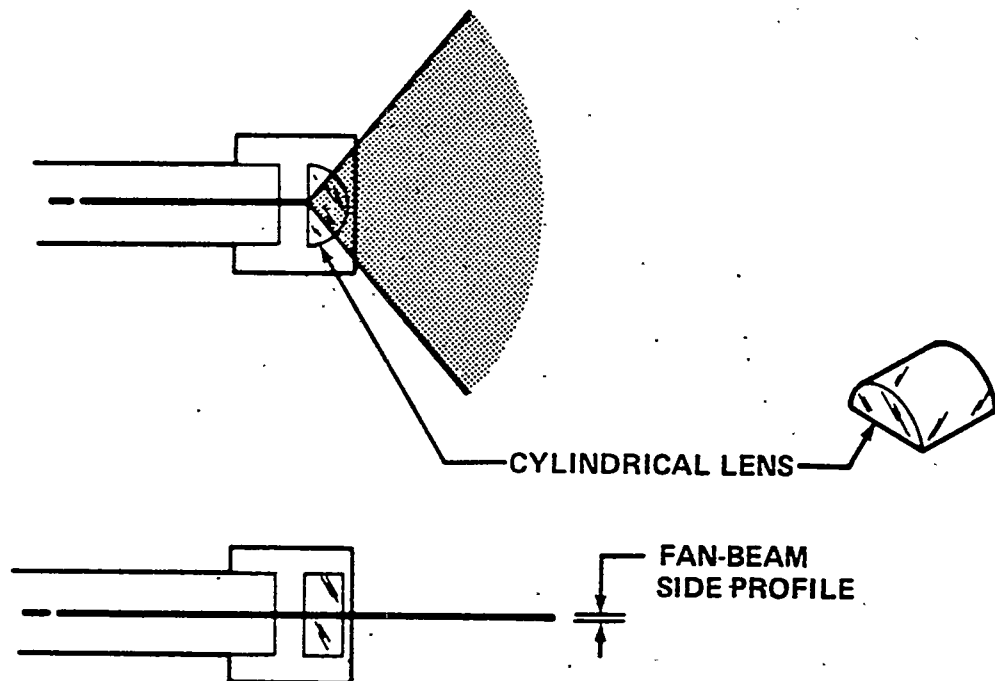
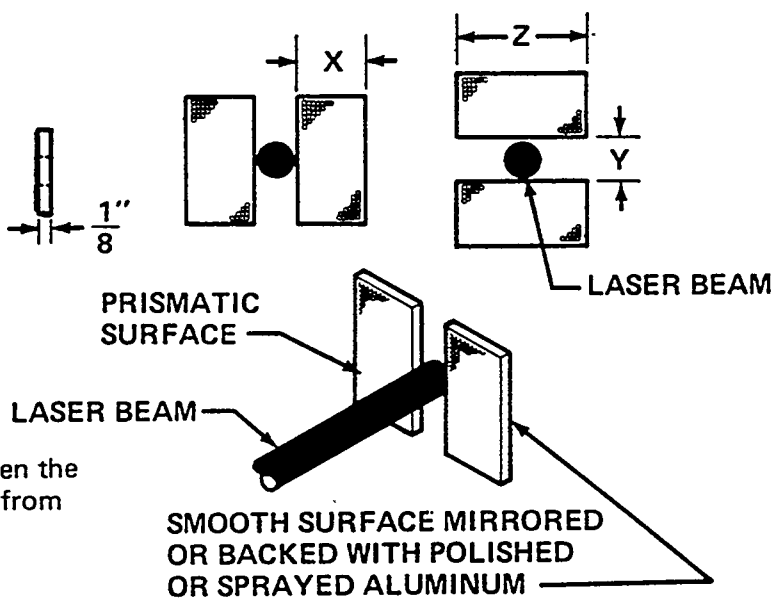
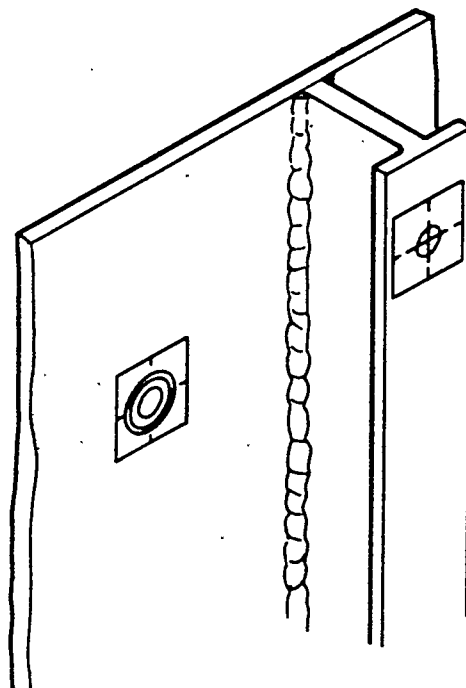
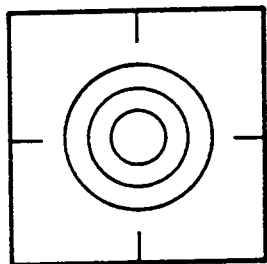
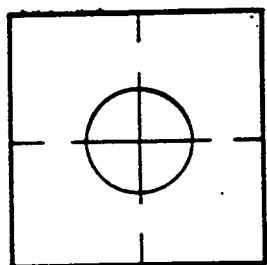
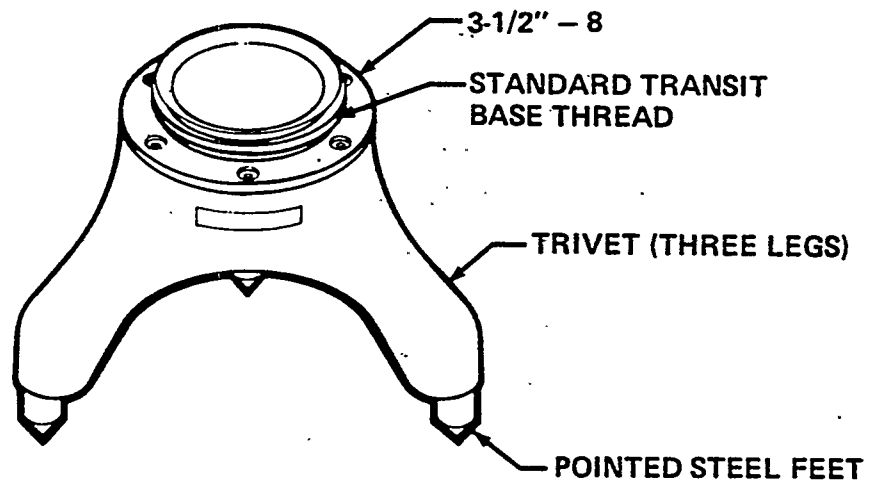


Figure 2-27: Fan-Shaped Laser Beam Lens Attachment



- Dimensions X, Y, and Z are dependent on distance of target from observer.
- Visual targets are for use when the observer is at some distance from the target.

Figure 2-28: Stick-On Visual Targets



- Bases may also be used to support Holding Bracket illustrated in Figure 2-6.

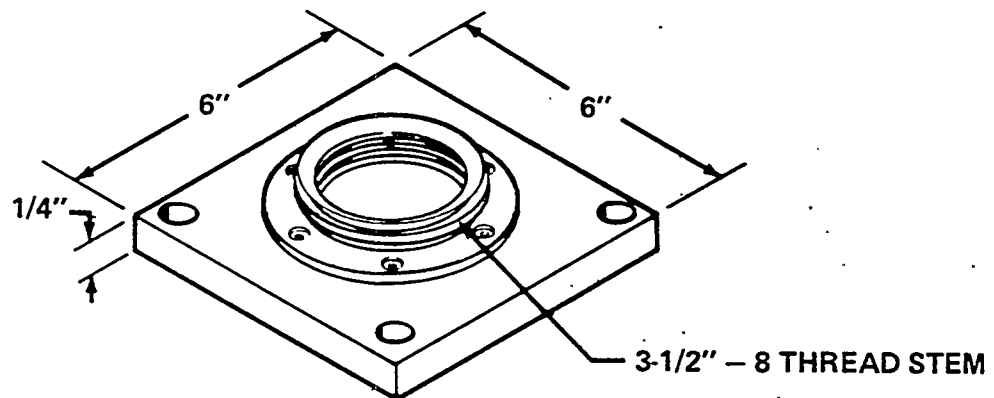


Figure 2-29: Low-Application Mounting Bases.

2.3 ACCESSORIES FOR LASER LEVEL

Accessories for the laser level are identical to those specified for the laser transit except for the calibration target. .

2.4 ACCESSORIES FOR LASER

Alignment laser accessories that can be used with the laser are:

- Reference point setting assembly (Figure 24) for holding visual targets only
- Adjustable target holder (Figure 2-8) for holding visual targets only
- Single-axis electronic detector–wand (Figure 2-1 4)-for use over a limited range where the beam diameter is commensurate with the photo cell aperture
- Visual targets illustrated in both Figures 2-15 and 2-28
- Vertical-hanging mirror (Figures 2-18 and 2-19)
- First-surface precision mirror (Figure 2-20)
- Planing penta prism (Figure 2-24) for use over a limited range where beam diameter is commensurate with prism aperture
- Mounting bases (Figure 2-25) for use in conjunction with vee blocks or universal brackets (Figure 2-7)

2.5 ESTABLISHING REFERENCE POINTS

A reference point is defined by the interception of a line and a plane. The alignment laser, transit laser, level, and simple laser are all useful for this application.

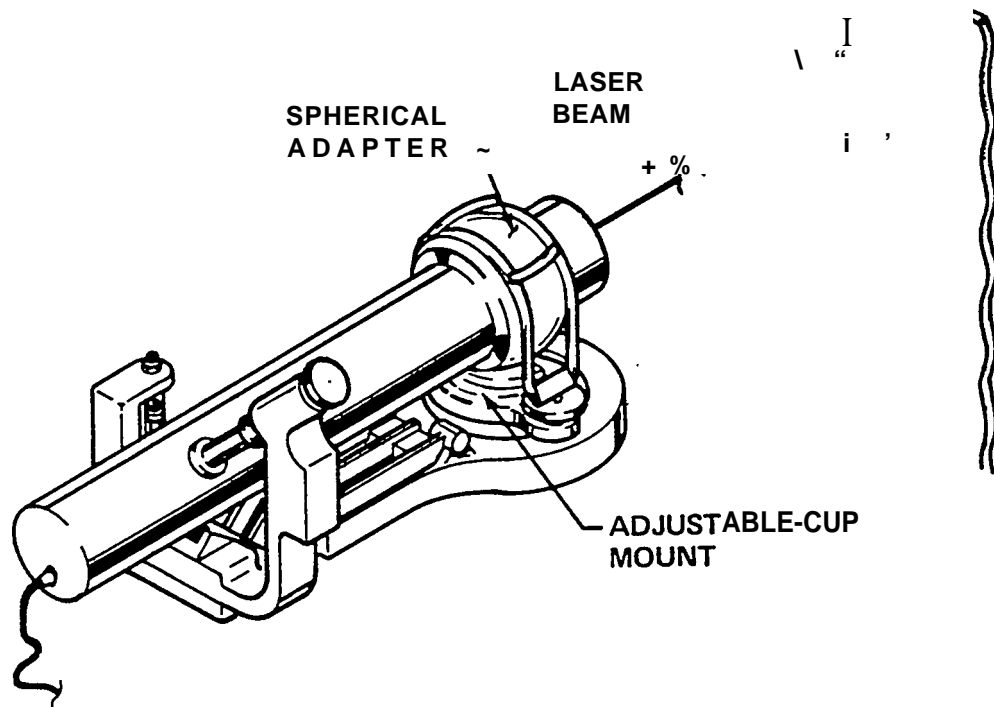


Figure 2-30: Establishing a Reference Point With the Alignment Laser

2.6 ESTABLISHING REFERENCE LINES

A reference line is defined by two points, A and B.

2.6.1 With the Alignment Laser

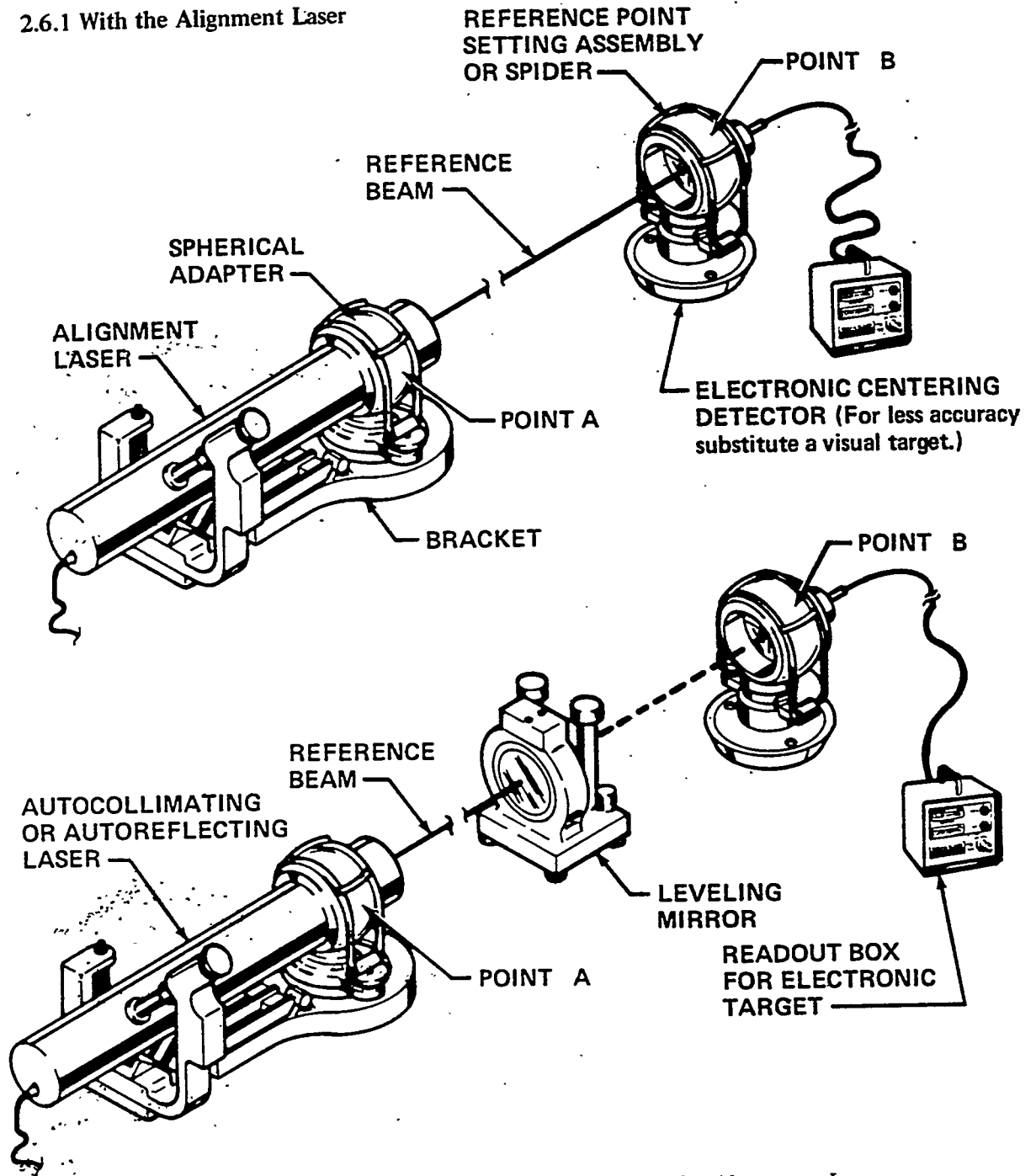


Figure 2-31: Establishing Reference Lines With the Alignment Laser

2.6.2 With the Transit Laser

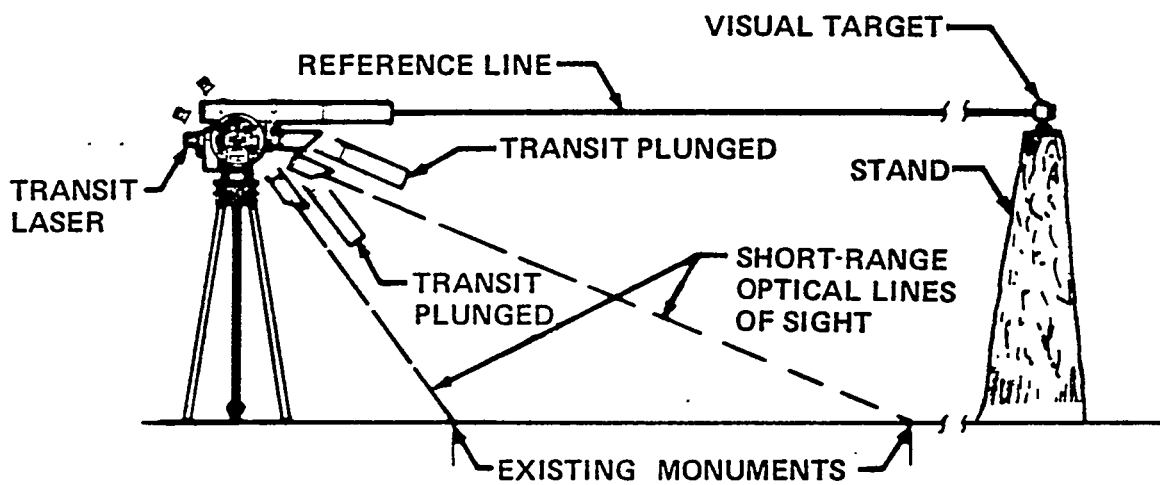
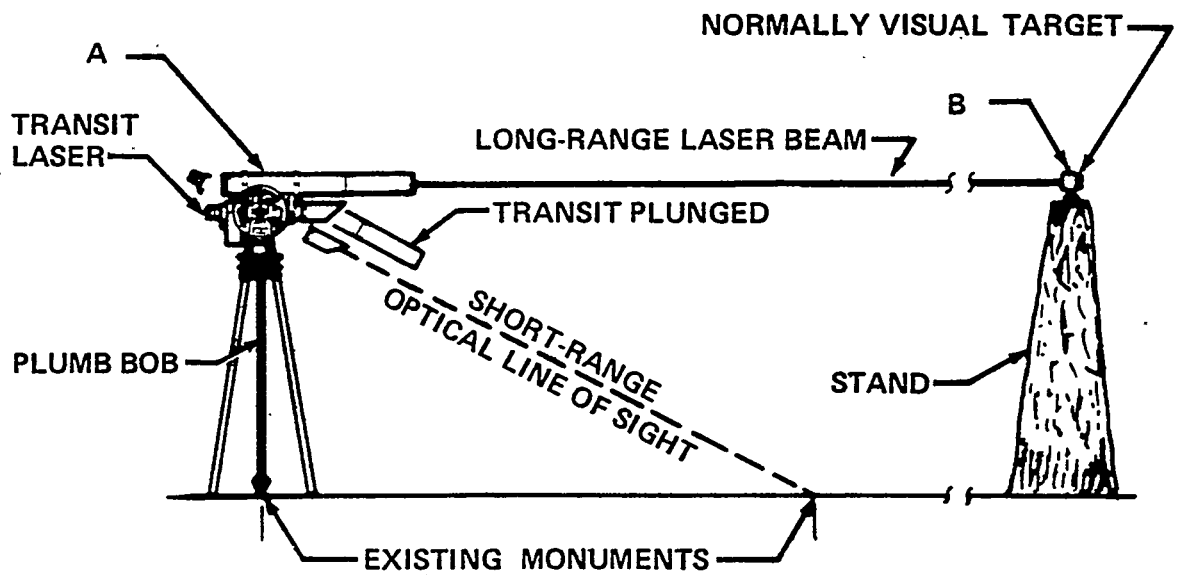


Figure 2-32: Establishing Reference Lines With the Transit Laser

2.6.3 With the Laser Level

Only level reference lines may be established with the laser level. Its application is identical to that for the transit laser except that it is limited to use with monuments existing in a bulkhead only, for example, the walls of a graving dock.

2.6.4 With the Laser

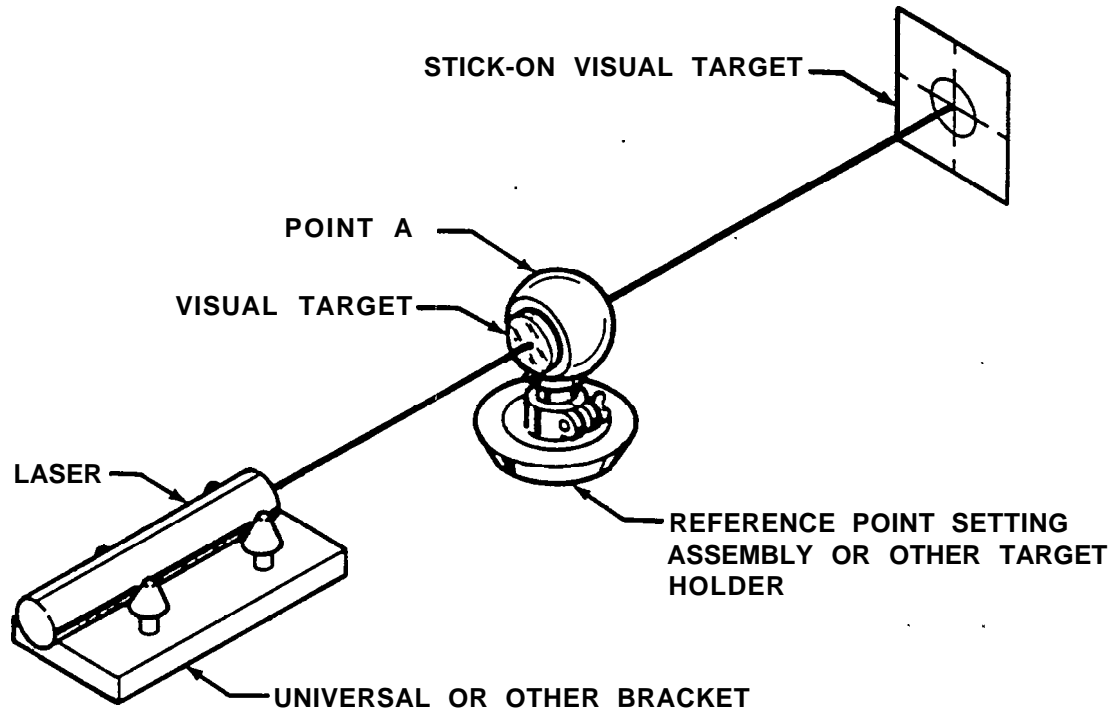


Figure 2-33: Establishing Reference Lines With the Simple Laser

2.7 ESTABLISHING REFERENCE PLANES

A plane is defined by three known points: A, B, and C or by a line AB and a point C.

2.7.1 With the Alignment Laser

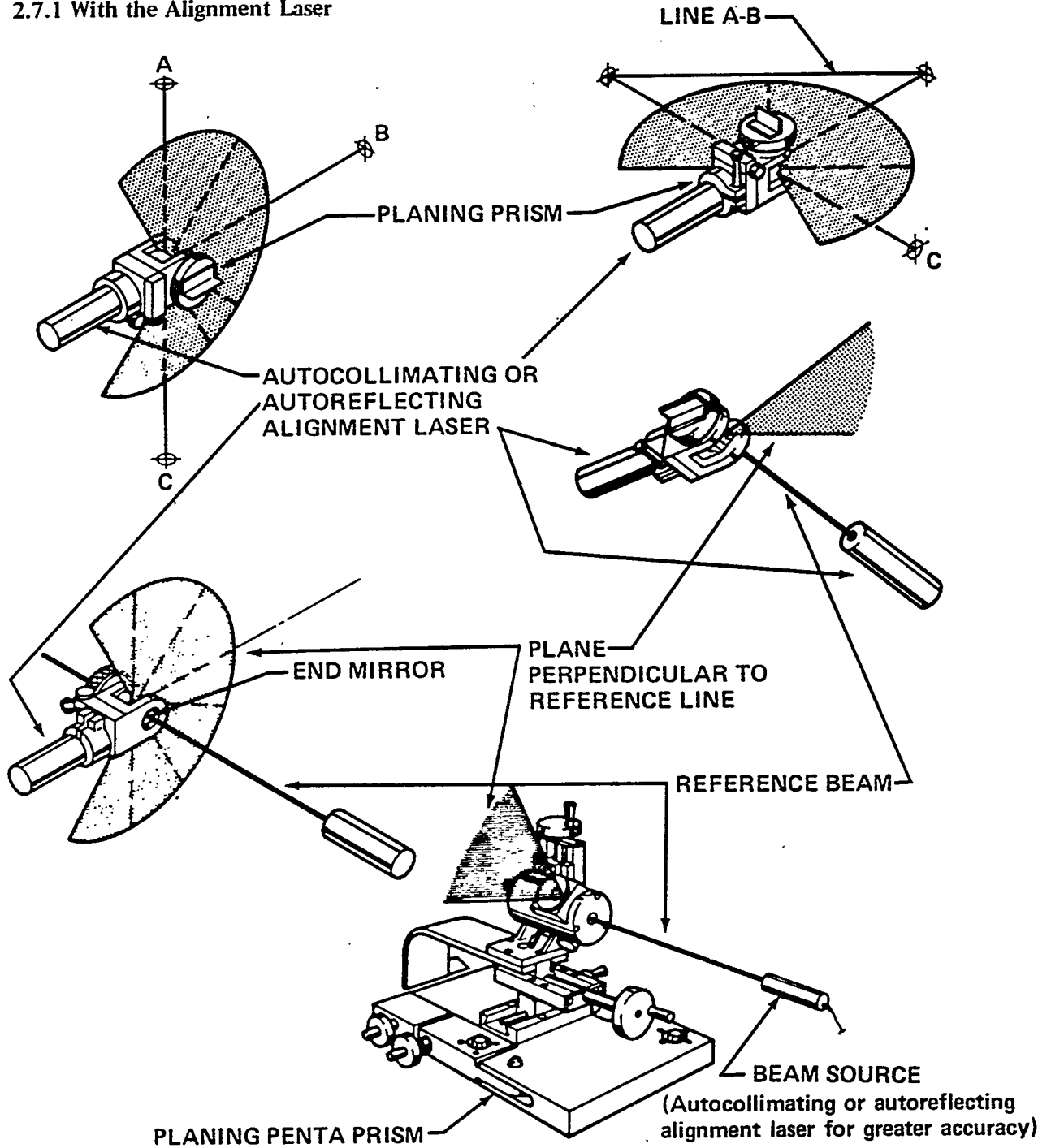
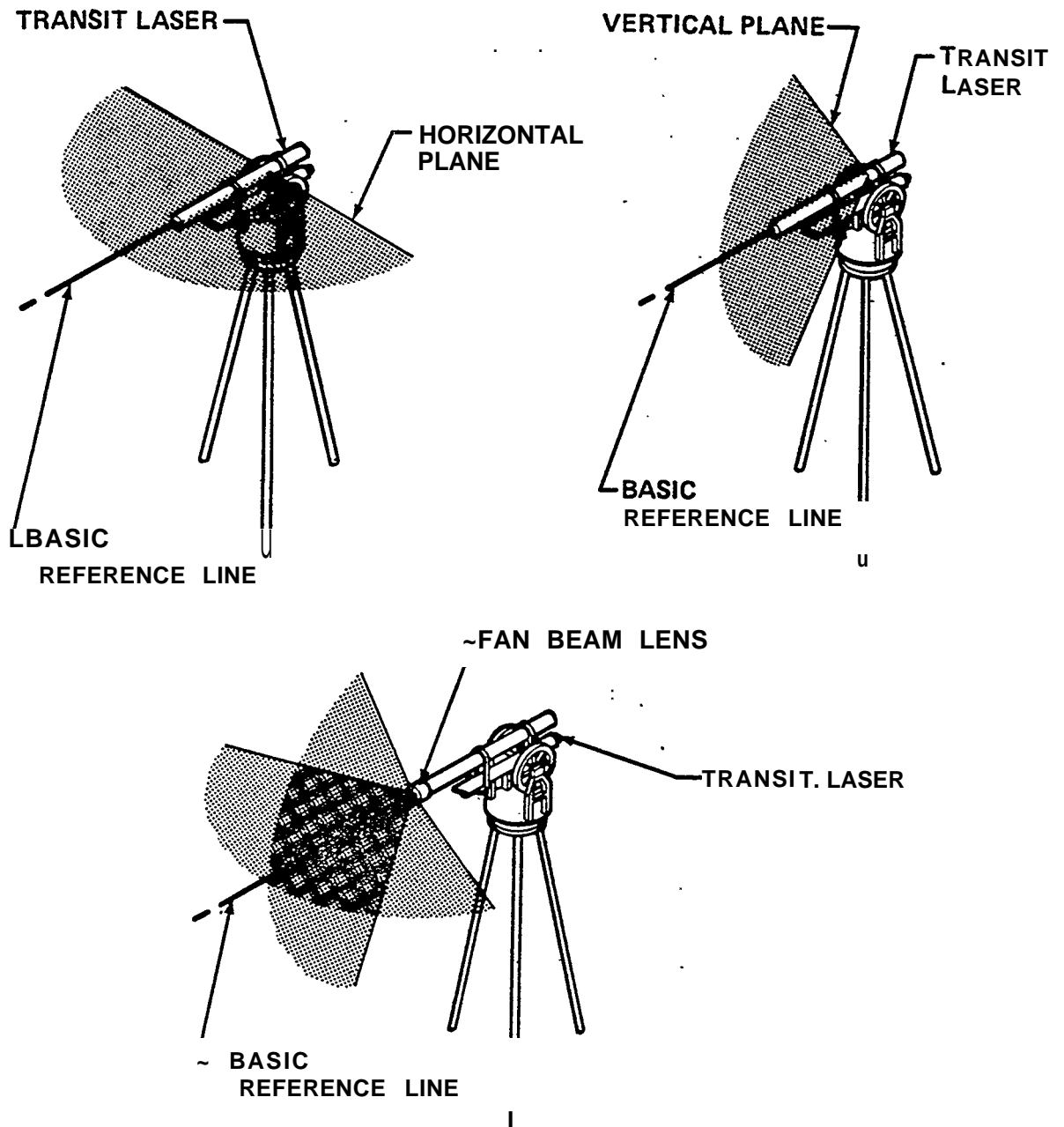


Figure 2-34: Establishing Reference Planes With the Alignment Laser

2.7.2 With the Laser Transit



- The plane may be skewed to any orientation.

Figure2-35: Establishing Reference Planes With the Transit Laser

2.7.3 With the Laser Level

A plane may be generated precisely with the laser level in its horizontal orientation only. The fan-beam lens can also be adapted to generate skewed planes around horizontal lines only.

2.7.4 With the Laser

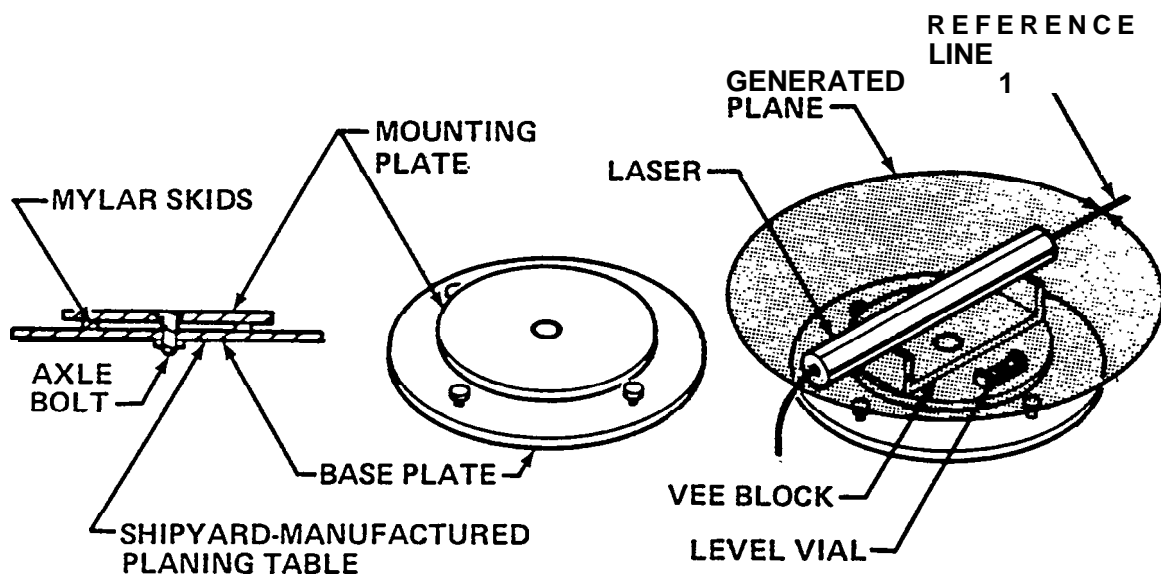


Figure 2-36: Establishing Reference Planes With the Simple Laser

2.8 MEASURING DISTANCES FROM LINES AND PLANES

The same techniques are used to measure distances from lines and planes. These techniques can be applied with all laser beam sources (see Figures 2-37 and 2-38).

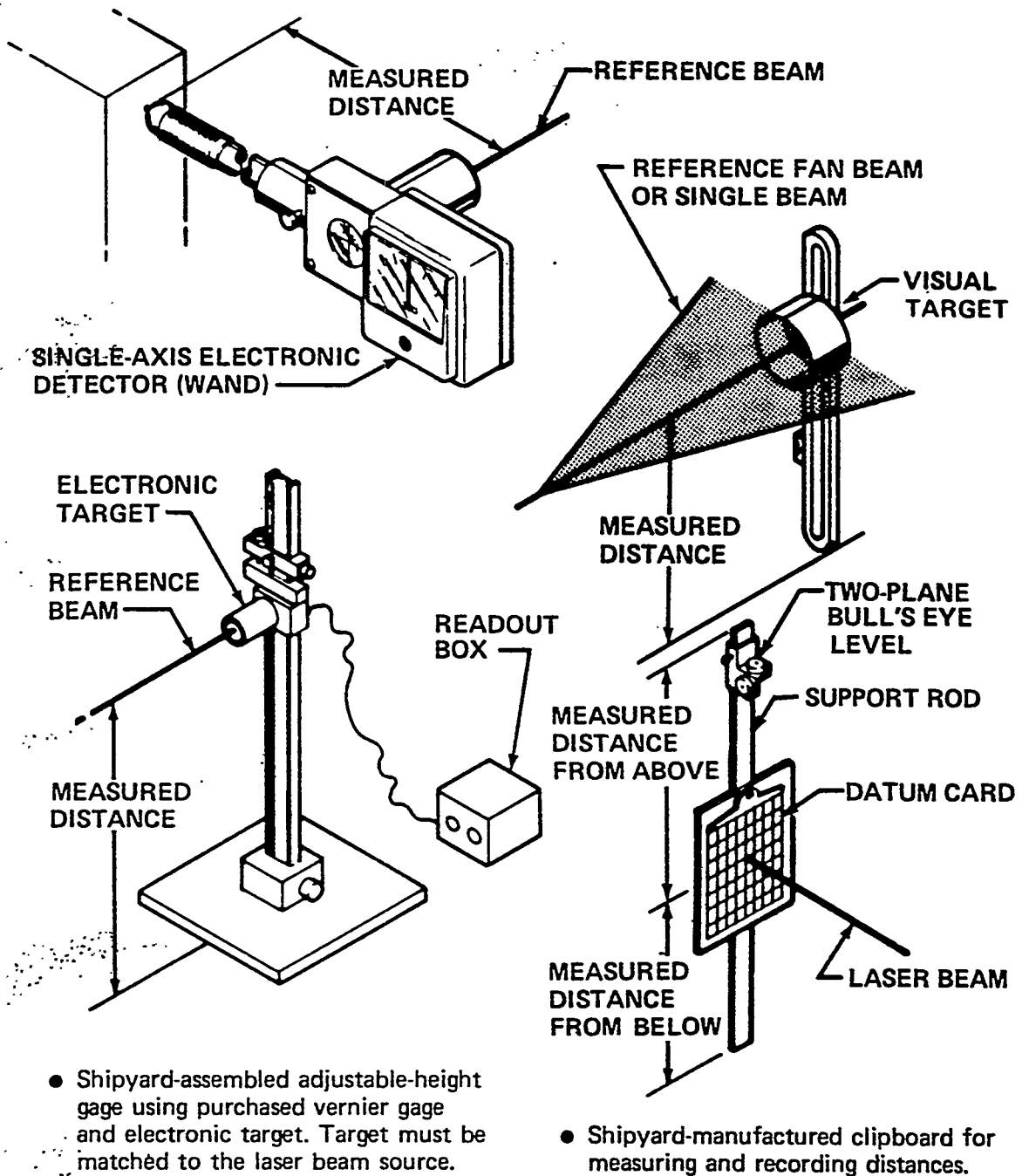
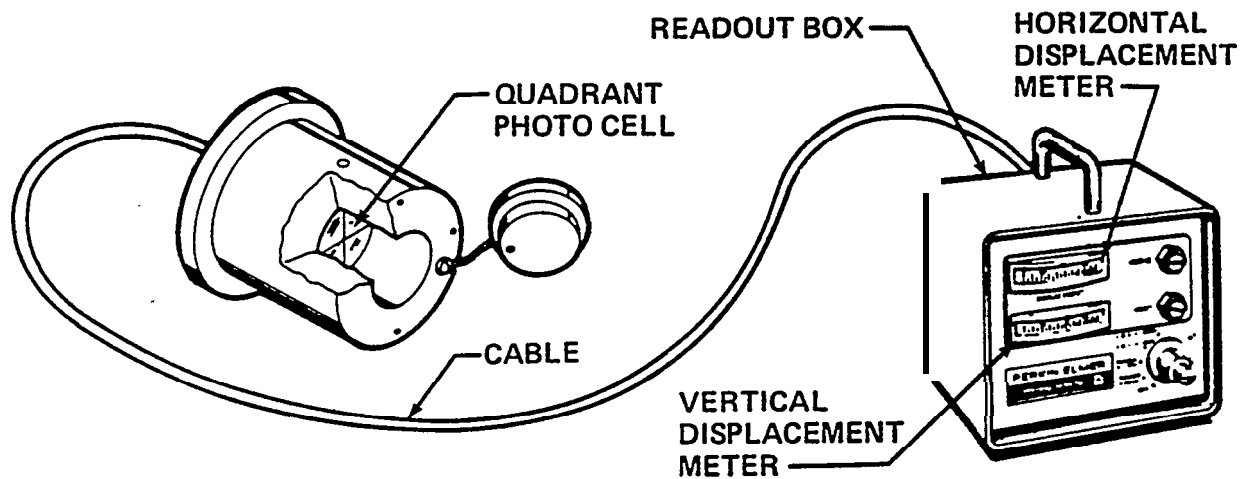
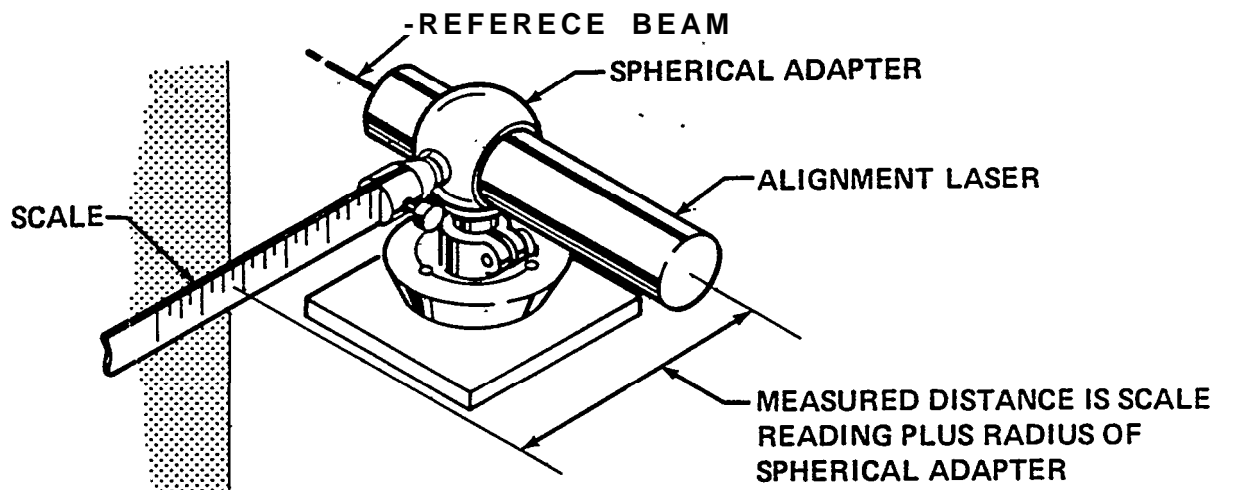


Figure 2-37: Measuring Distances From Reference Lines and Planes



- The electronic centering detector (electronic target) measures displacement of the beam from two axes. It measures in fine increments and in some systems through a range up to 1/2 inch.

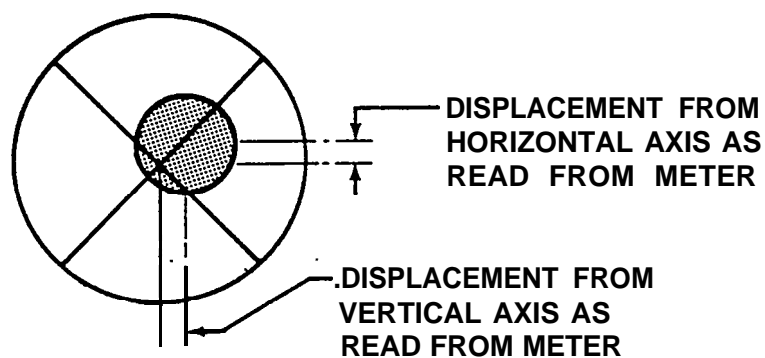
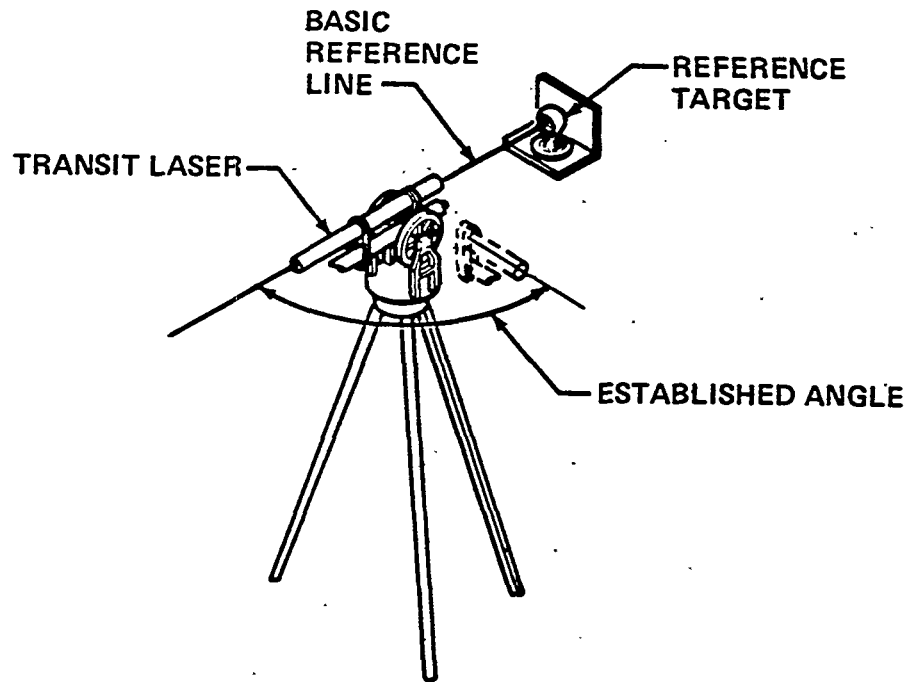


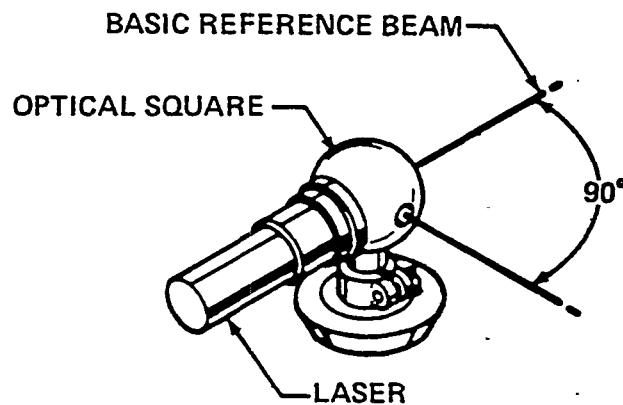
Figure 2-38: Measuring Distances from Reference Lines and Planes

2.9 MEASURING ANGLES FROM REFERENCE LINES AND PLANES

See Figures 2-39 and 2-40.

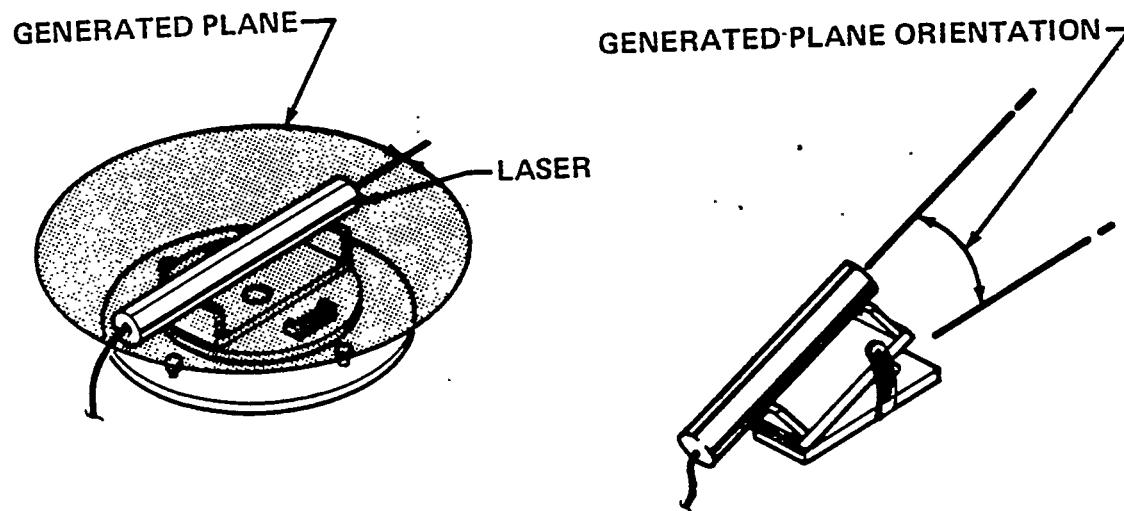


- Only the transit laser can be used to accurately measure any angle from a reference line, and it is limited to establishing angles from lines that exist in two planes, i.e., horizontal or vertical.



- Establishing a 90° line from a reference line.

Figure 2-39: Measuring Angles From Reference Lines and Planes With Conventional Equipment



- Various devices can be made and calibrated in the shipyards that would have sufficient accuracy for hull structure.

Figure 2-40: Shipyard-Manufactured Devices for Measuring Angles From Reference Lines and Planes

2.10 MEASURING RANGES

Practical laser devices for measuring linear distances, as of mid-1973, are limited to those employing two principles of electromagnetic radiation: electronic distance-measuring equipment and the laser interferometer.

The electronic distance-measuring equipment (EDM), Figure 2-41, generates an infrared beam of electromagnetic radiation that is applied exactly like a radar. It can be attached to a transit telescope or readily mounted in an adjustable target holder or other reference position with shipyard-manufactured adapters. Based on developments through mid-1973, they are accurate to within $\pm 1/4$ inch over a range of 3 feet to 1 mile. Application is suggested for:

- Spacing of blocks in building docks
- Measurement across hatches or to high overheads where access with staging would otherwise be required
- Measurement to ensure overall dimensions for an integral number of cargo containers or barges that are to be installed in a single hold
- Verification of hull-structure dimensions by inspectors and admeasurers.

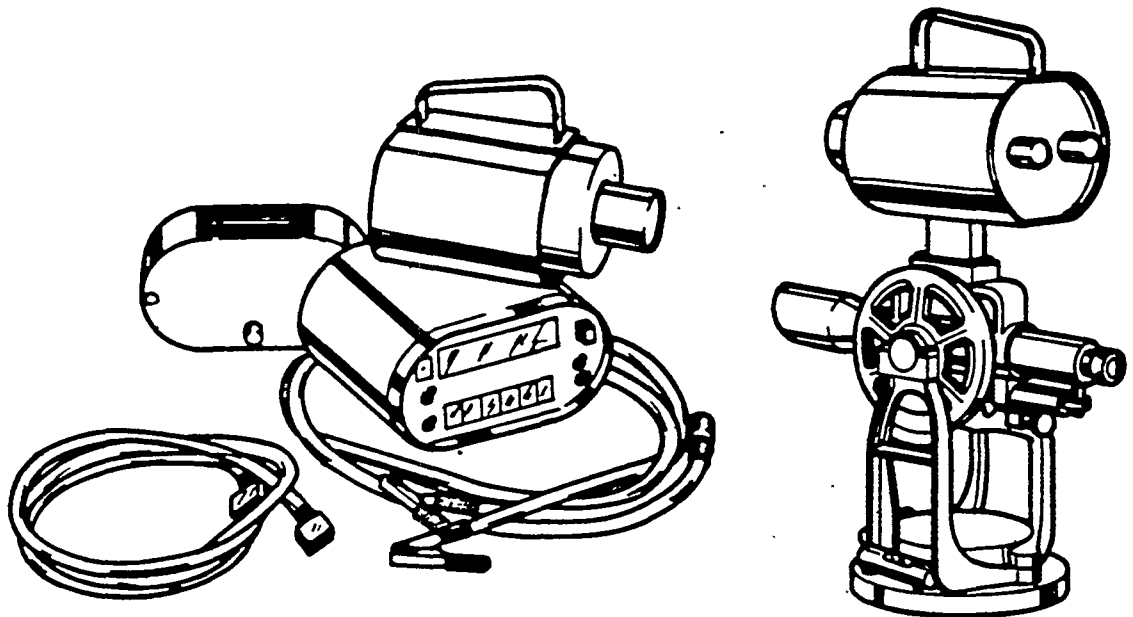


Figure 2-41: Electronic Distance Measuring Equipment

The laser interferometer (Figure 2-42) is a highly precise, relatively expensive, linear measuring device. It is calibrated for use with a special reflecting target and is limited to measuring distances traversed by the target over a very precise straight-line path. They can achieve better than ± 0.0001 -inch accuracy. Application is suggested for:

- Linear measurement on machine tools having precisely finished rails or ways
- Verification of linear control devices, such as in numerical control turning machines
- Use as a linear measurement standard by quality-control people
- Eventually, use as a follow-up device to override the stepping-motor system in numerical control machines.

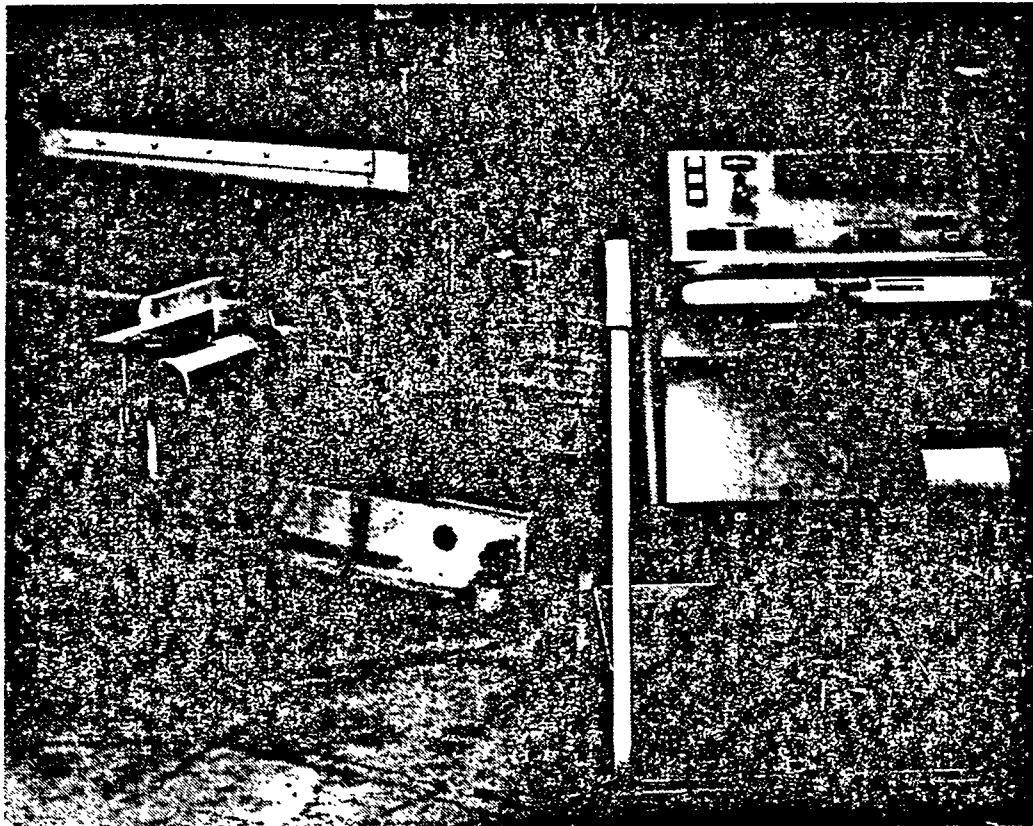


Figure 2-42: Laser Interferometer Precise Distance Measuring Equipment

It appears that, as of mid-1973, at least for the near future, nonlaser devices such as the electromechanical measuring tape (Figure 2-43) are far more practical for shipbuilding applications. These are accurate to ± 0.001 inch over a range from 0 to 20 feet. They can be obtained for greater ranges. Application is suggested for situations where the digital readout capability is advantageous.

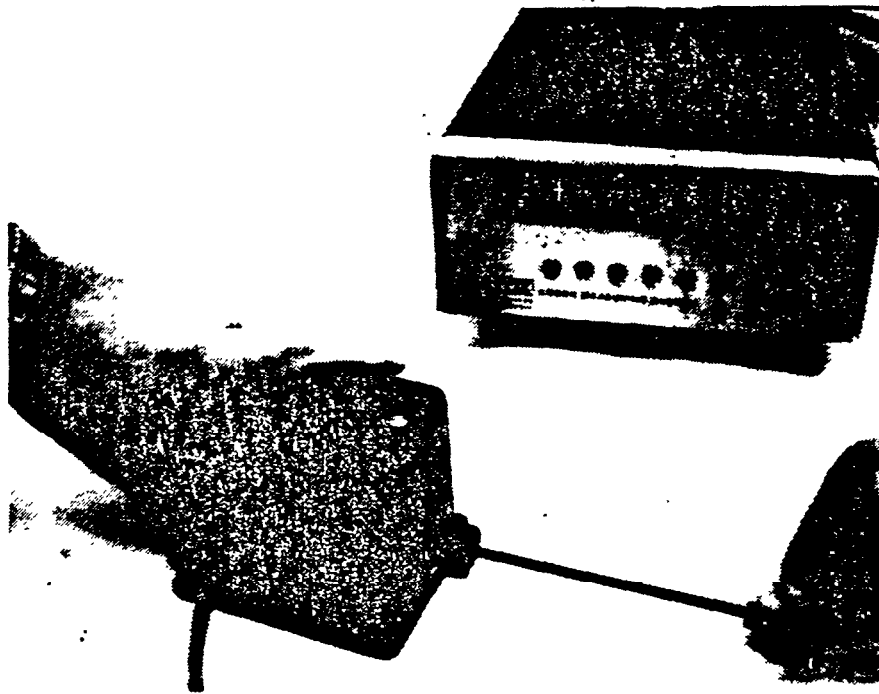


Figure 2-43: Electromechanical Distance Measuring Device

3.0 SUGGESTED LASER APPLICATIONS

3.1 PROPULSION SHAFT ALIGNMENT WITH INBOARD-ACCESSIBLE STERN BEARING

3.1.1 Establishing a Reference Line Using Fixed Shipboard and/or Dock References

See Figure 3-1.

3.1.2 Joining the Stern Bearing Tunnel Section Erection Unit

See Figure 3-1.

The visual targets C and D are installed in the shop:

- On the axis of the tunnel if it is to be installed concentric with reference line AB
- Offset from the axis of the tunnel if the tunnel is to be installed other than concentric to reference line AB.

Visual targets properly designed for the distances they are used from the beam source will readily detect deviations of # 1 millimeter (see Appendix C). Normally, both targets can have the same diameter holes if they are within 50 feet of each other. Visual targets should be observed continually to monitor any movement of tunnel alignment during welding of the erection unit and until completion of all other welding in the vicinity.

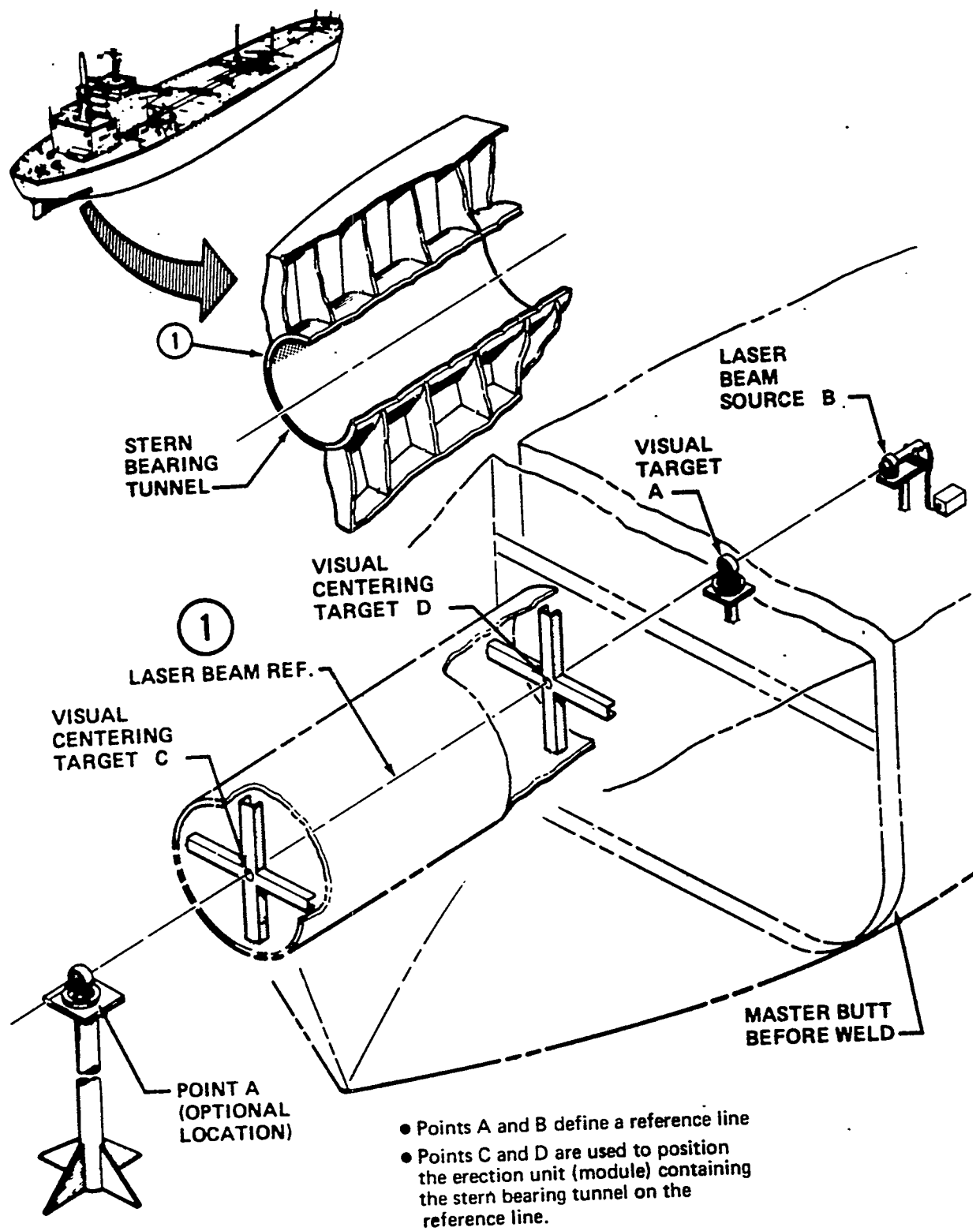


Figure 3-1: Establishing a Reference Line Using Fixed Shipboard and/or Dock References, (based upon an actual application).

3.1.3 Re-establishing the Repulsion-Shaft Reference Line to the Joined Stern Bearing Tunnel Erection Unit

The reference line has to be re-established based on the actual position of the stem bearing tunnel achieved. Depending on a particular shipyard's procedure, the reestablished line will be used either for first positioning the after-frame ring or for first positioning the reduction gear. In both cases, since machinery tolerances are generally ± 0.005 inch, an alignment laser and electronic targets should be used to establish:

- 1 Reference line for first positioning the after stem ring, see Figure 3-2
- 1 Reference line for first positioning the reduction gear (solid shaft), see Figure 3-3
- 1 Reference line for first positioning the reduction gear (hollow shaft), see o Figure 3-4
- 1 Reference line if the reduction gear foundation is to be finished neat, see Figure 3-5

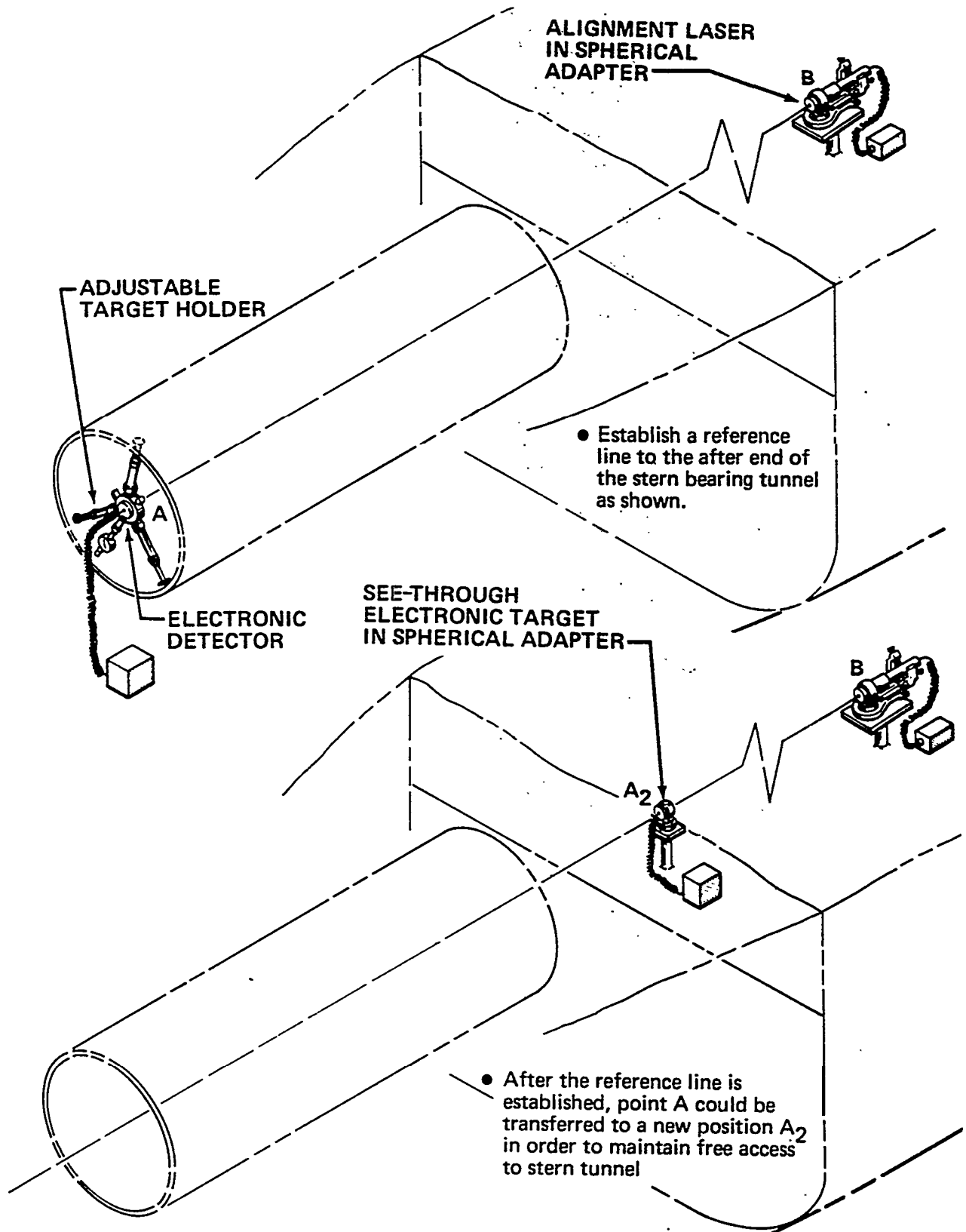


Figure 3-2: Establishing a Reference Line for First Positioning After Stern Ring, (based upon an actual application).

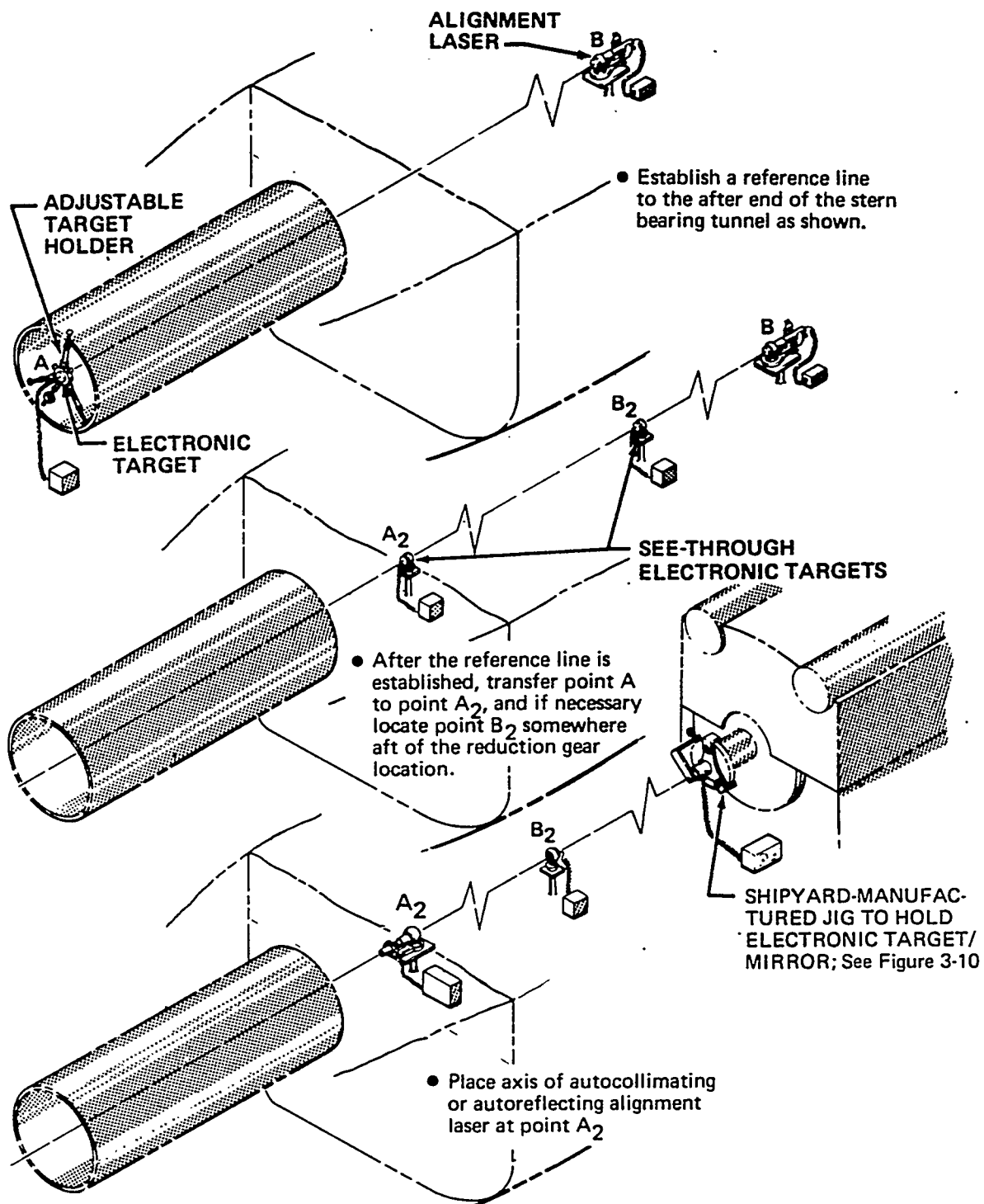


Figure 3-3: Establishing a Reference Line for First Positioning Reduction Gear (Solid Shaft)

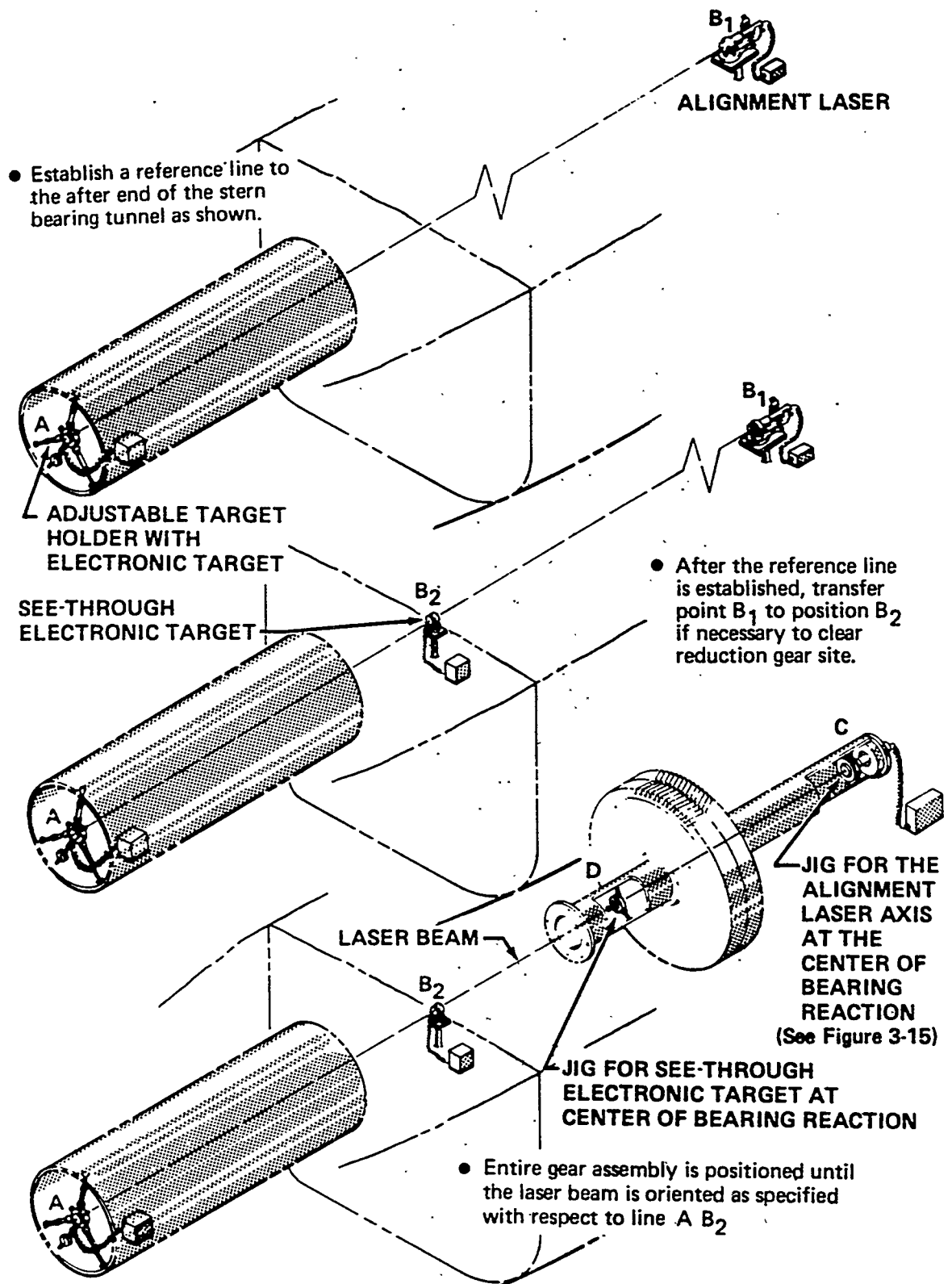


Figure 3-4: Establishing a Reference Line for First Positioning Reduction Gear (Hollow Shaft), (based upon an actual application).

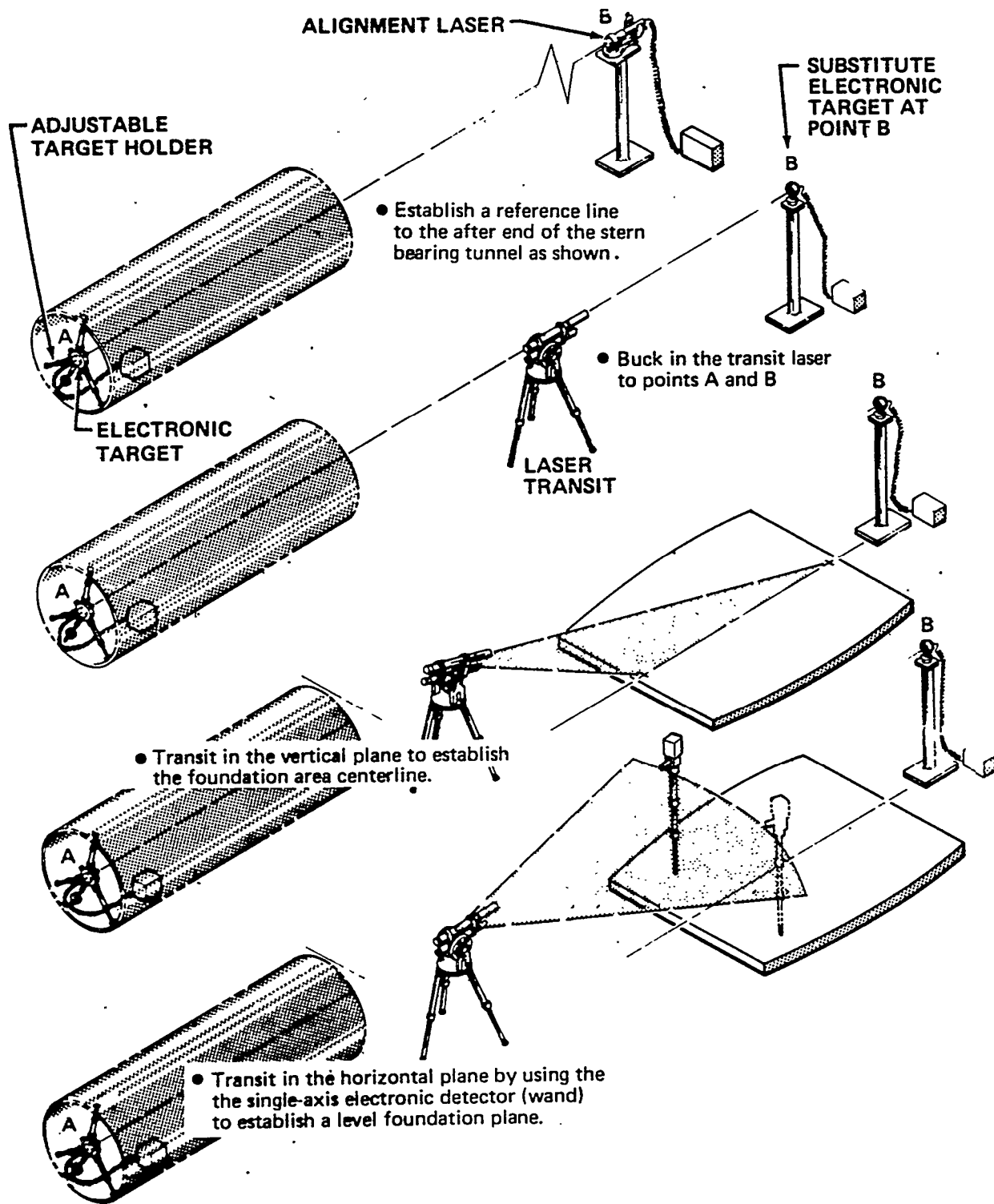
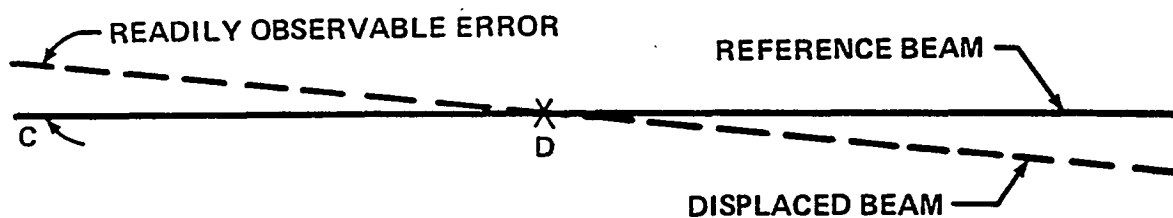
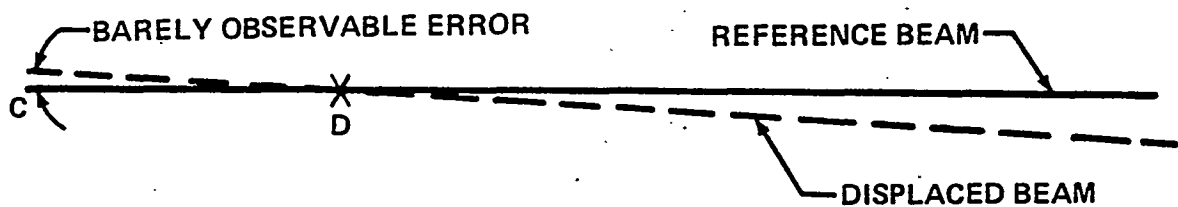


Figure 3-5: Establishing a Reference Line if Reduction Gear Foundation Is To Be Finished Neat

3.1.4 Attaching the After-Frame Ring

Positioning and maintaining alignment during welding of the machine-finished after-frame ring requires precision techniques. Because the after-frame ring is relatively short, the two points required to control its alignment are relatively close to each other. Consideration must be given to avoid parallax error, Figure 3-6.

Two methods are possible. The preferred method (Figure 3-7) employs “a mirror mounted in a precision jig, a” see-through electronic target, and either an autocollimating or autoreflecting alignment laser. An inherent advantage with the mirror is that the angle detected is easier to read because it is always twice-the angle being measured, Figure 3-8. The second method (Figure 3-9) can be accomplished with an ordinary electronic target, a see-through electronic target, and without either autocollimating or autoreflecting capability, provided the alignment laser is relocated’ as close as practicable to the after-frame ring. Sometimes this is not desirable because of access required and adverse effects of welding in the vicinity.



- The closer detectors C and D are in relationship to the total distance from the laser, the greater the probable error in placing any structure to a reference line.
- In aligning short-length cylindrical sections using two centering detectors, care must be taken to place the laser as close to one of the targets as possible.

Figure 3-6: Parallax Error in Two-Point Angular Alignment

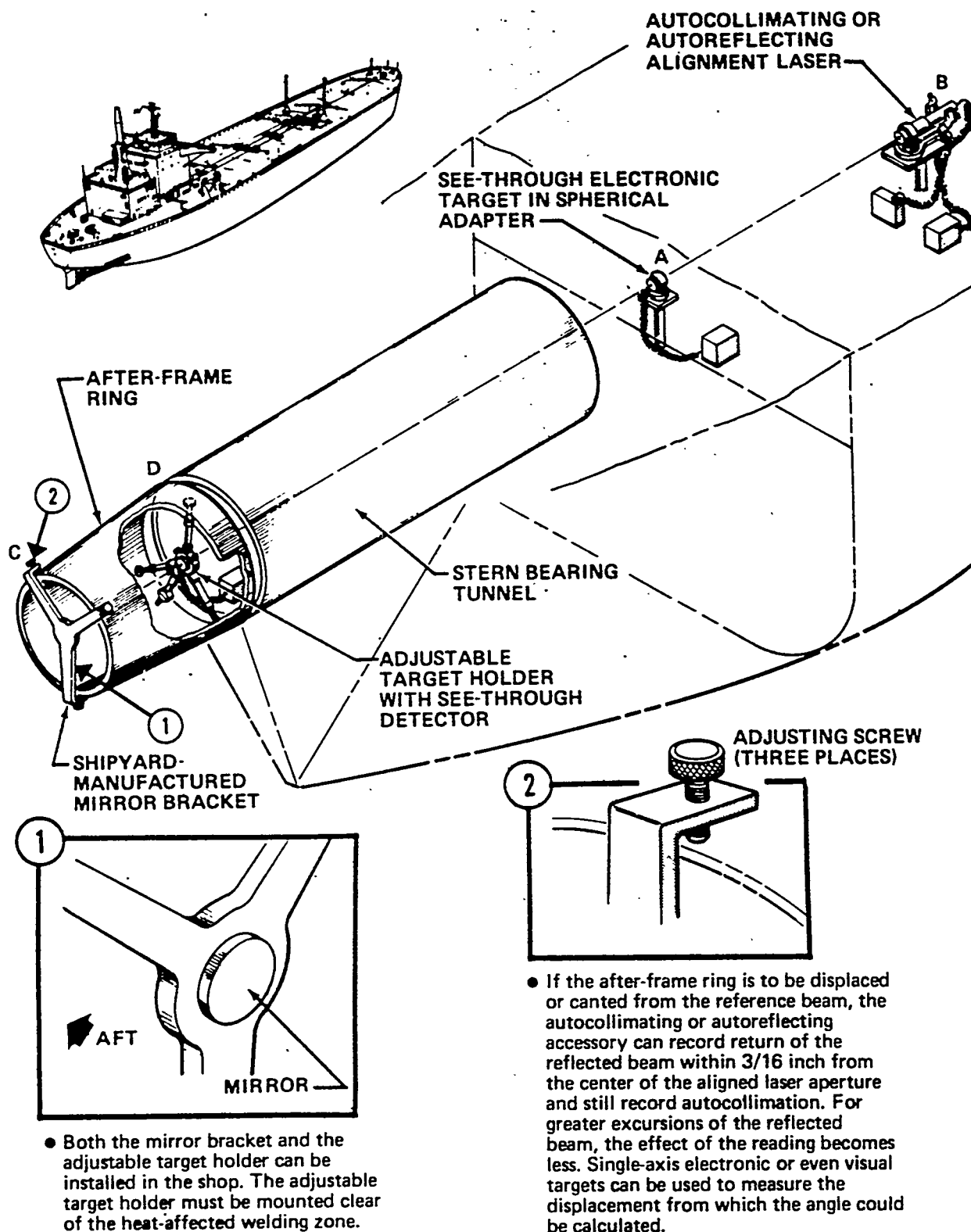


Figure 3-7: Joining After-Frame Ring Using See-Through Target and Mirror

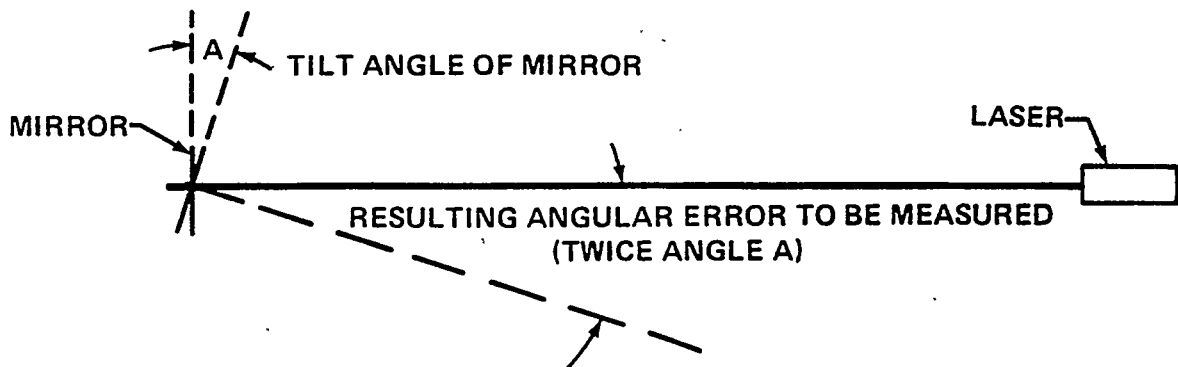


Figure 3-8: Autocollimation Angular Measurement

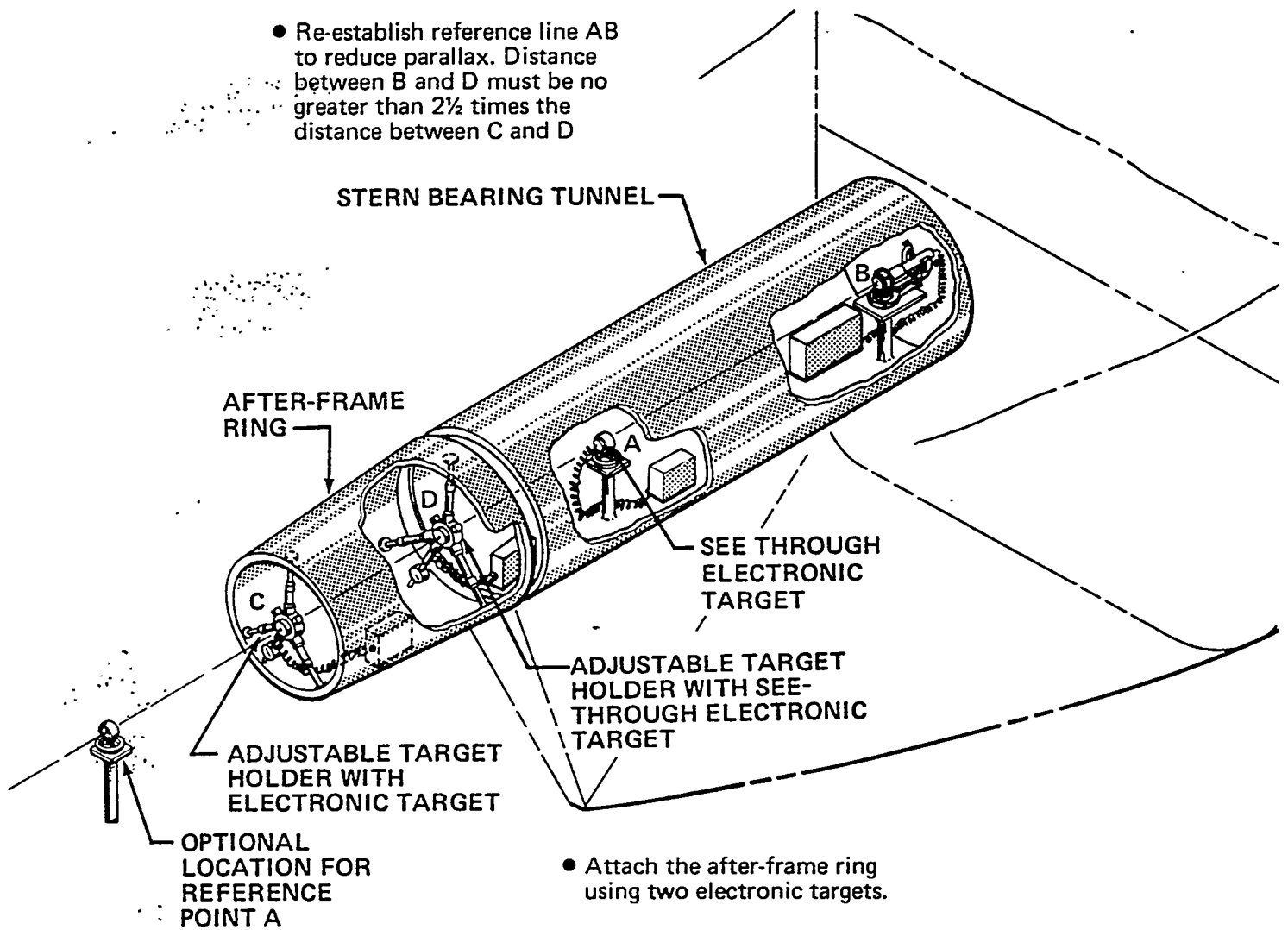


Figure 3-9: Joining After-Frame Ring Using Two Electronic Detectors, (based upon an actual application).

3.1.5 Aligning the Reduction Gear (Solid Shaft)

Either of two shipyard-manufactured jigs could be used, i.e., an electronic target and mirror holding jig (Figure 3-10) or an alignment-laser holding jig (Figure 3-1 1). The former is used when the reference beam is directed toward the reduction gear; the latter is used when it is desired to mount the *laser* source on the reduction gear and direct it aft.

Alternate use of the electronic target and mirror for centering and orienting the reduction-gear flange perpendicular to a reference beam is illustrated in Figure 3-12. Further, this figure illustrates how the reduction gear may be displaced from or set at an angle to a reference beam. Note. as illustrated in Figure 2-12, the electronic target has vertical and horizontal axes. The two readout meters correspond to these axes. If, for any reason, the reduction gear was rotated, care must be taken to interpret the meters as representing axes that have also been rotated.

Use of an alignment-laser holding jig is shown in Figure 3-13. Figure 3-14 illustrates how the reduction gear may be displaced from or set at an angle to a reference beam.

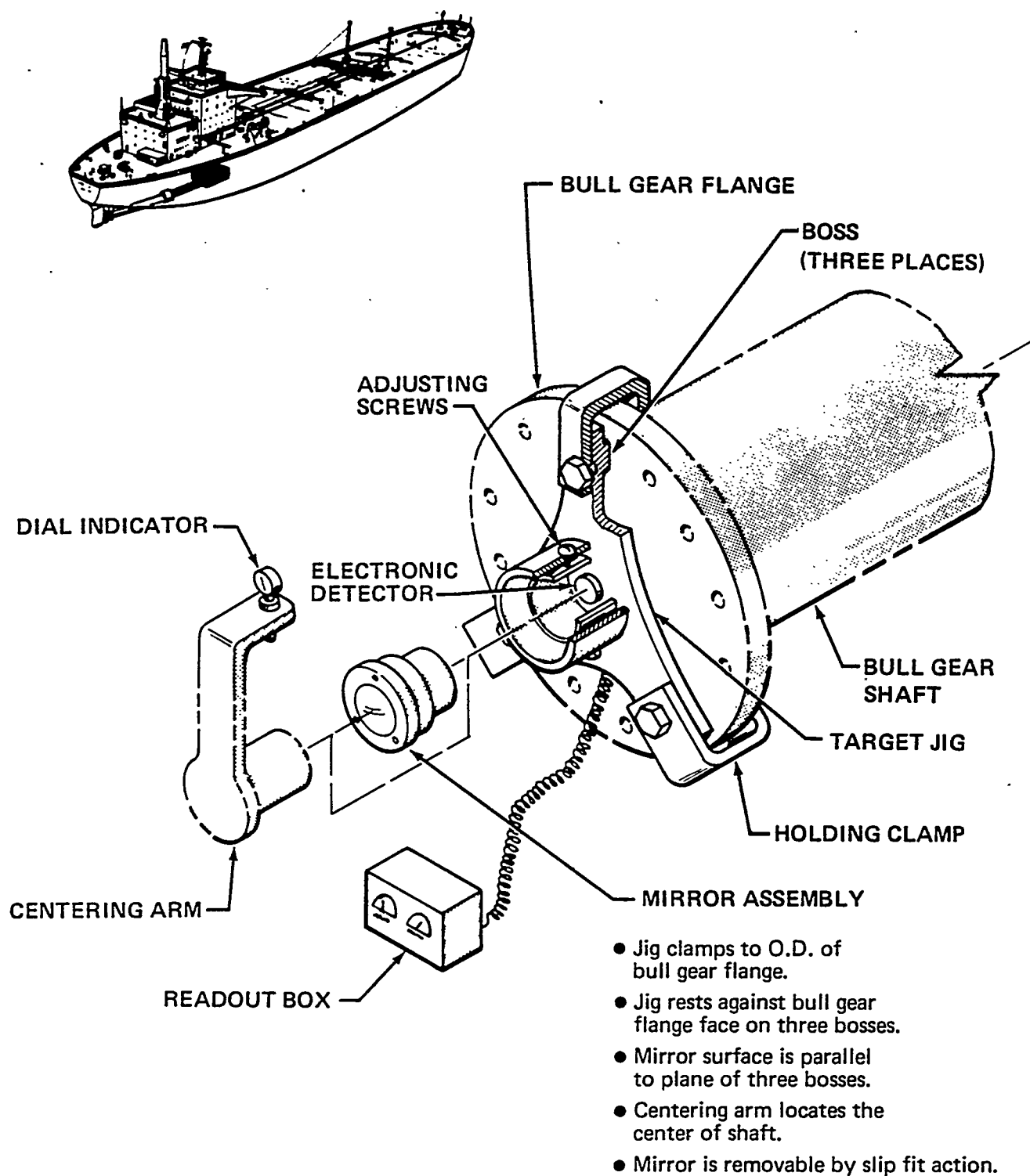
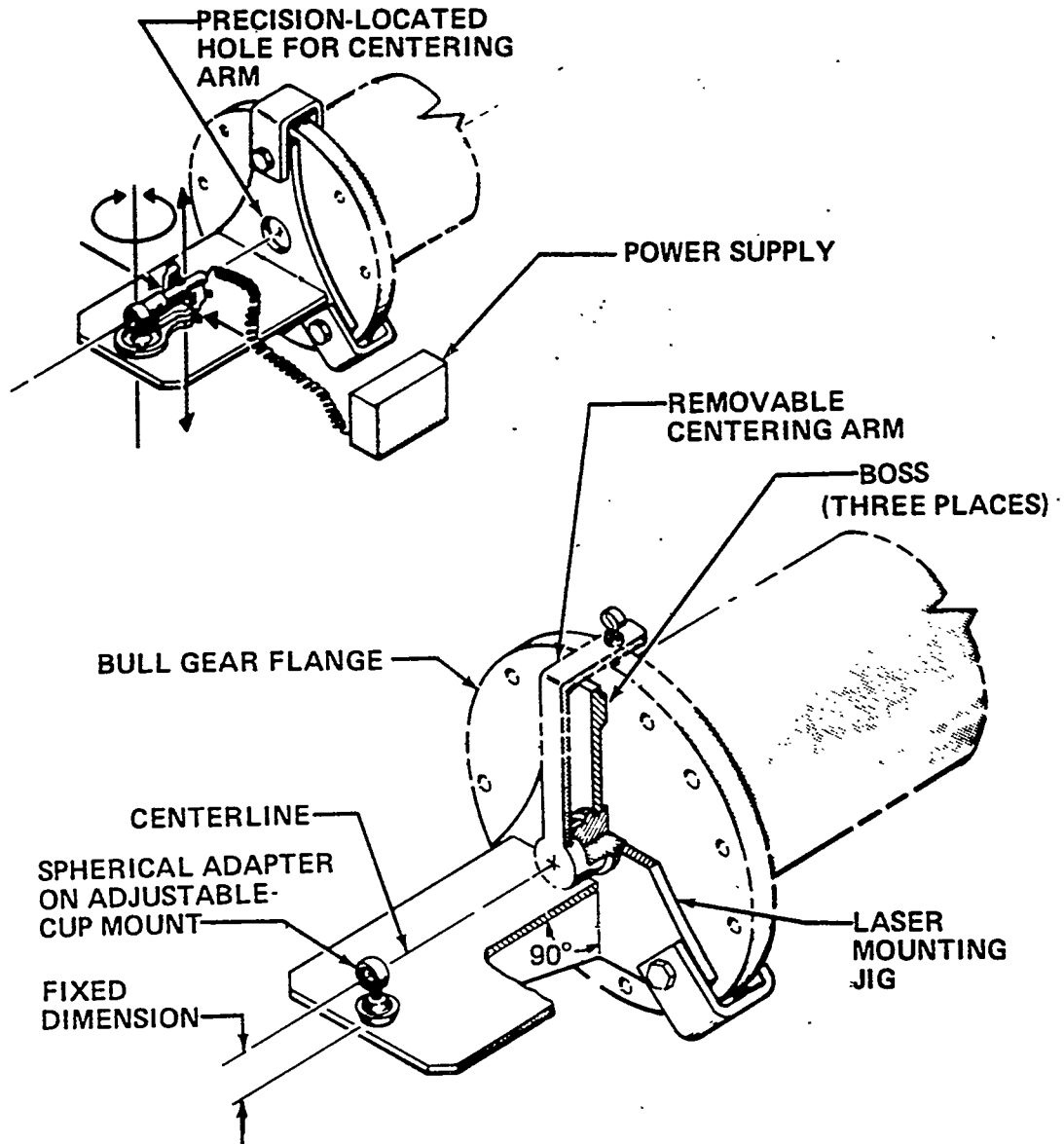


Figure 3-10: Bull Gear Mirror and Target Jig for Solid-Shaft Alignment



- Jig clamps to O.D. of bull gear shaft flange.
- Jig rests against bull gear shaft flange on three bosses.
- Spherical adapter is precisely located at the center axis of jig with an adjustable-cup mount.
- Rear end of laser rests on a fixture which provides vertical and horizontal adjustments.
- Centering arm can be used to adjust jig to center of shaft axis.
- Centering can be done by rotating bull gear and adjusting the alignment laser until the beam is coincident with the center of rotation.

Figure 3-11: Jig for Mounting Laser to Solid-Shaft Bull Gear

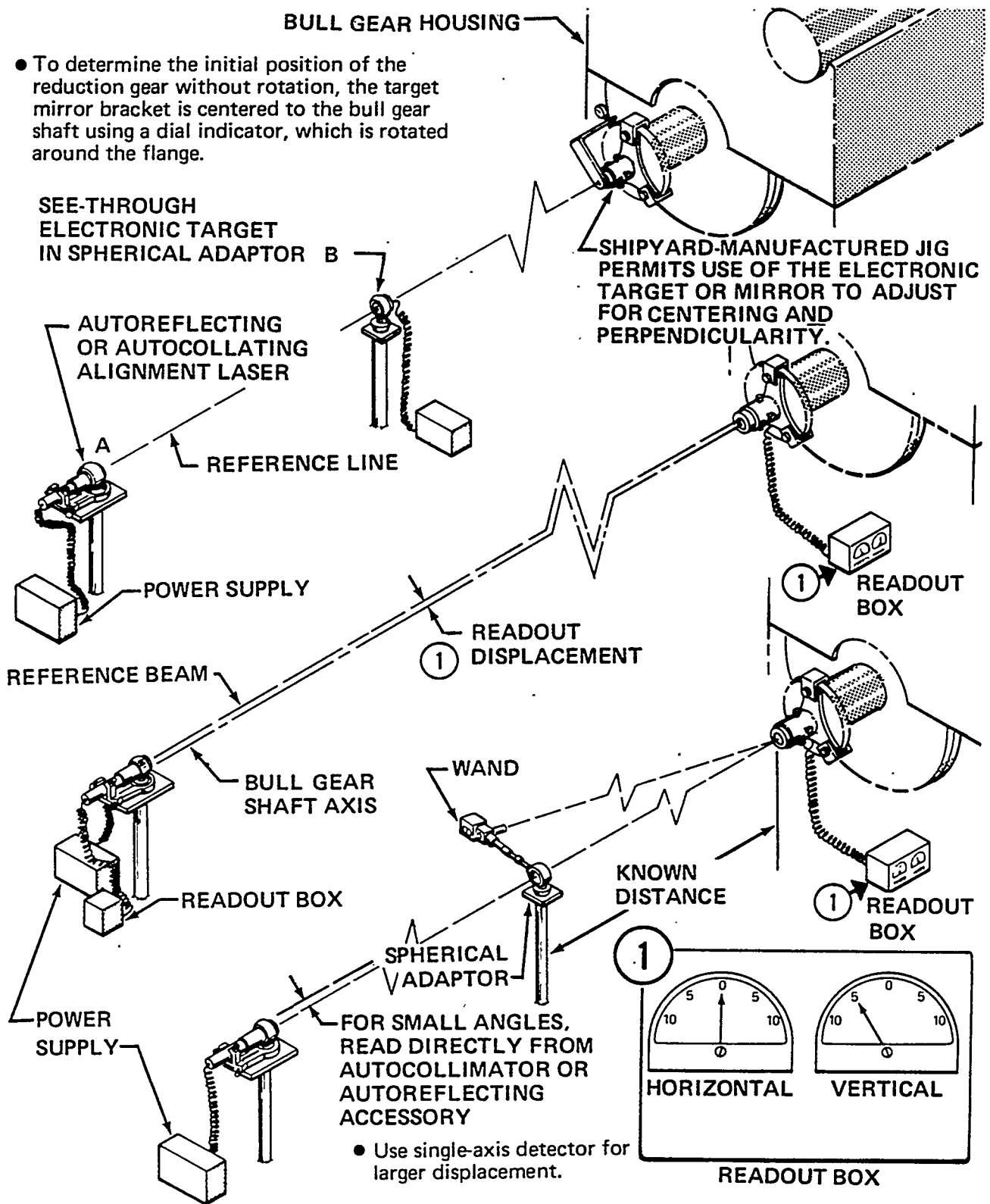
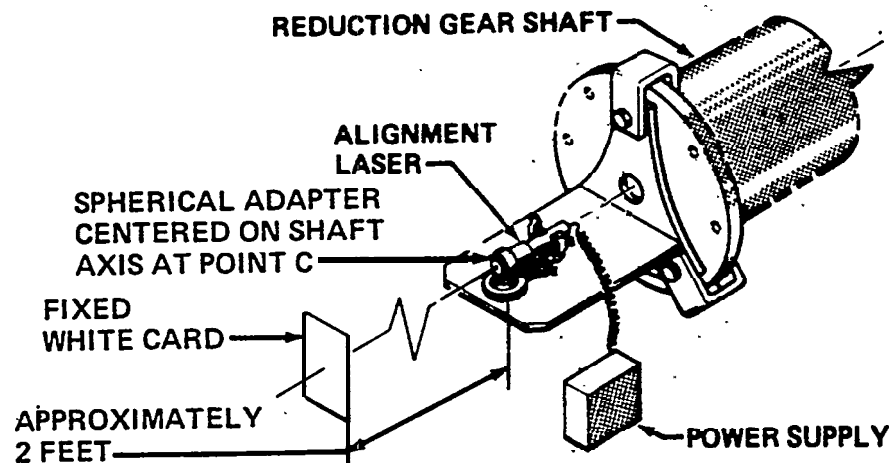


Figure 3-12: Alternate use of Electronic Target and Mirror for Orienting Reduction Gear Flange to Reference Beam



- Adjust laser bracket to roughly align beam concentric with shaft axis.
- Rotate shaft and adjust the laser bracket until the "spot" remains stationary on white card: this assures that beam is concentric with shaft axis.

Figure 3-13: Bull Gear Rotated to Align Laser to Shaft Axis

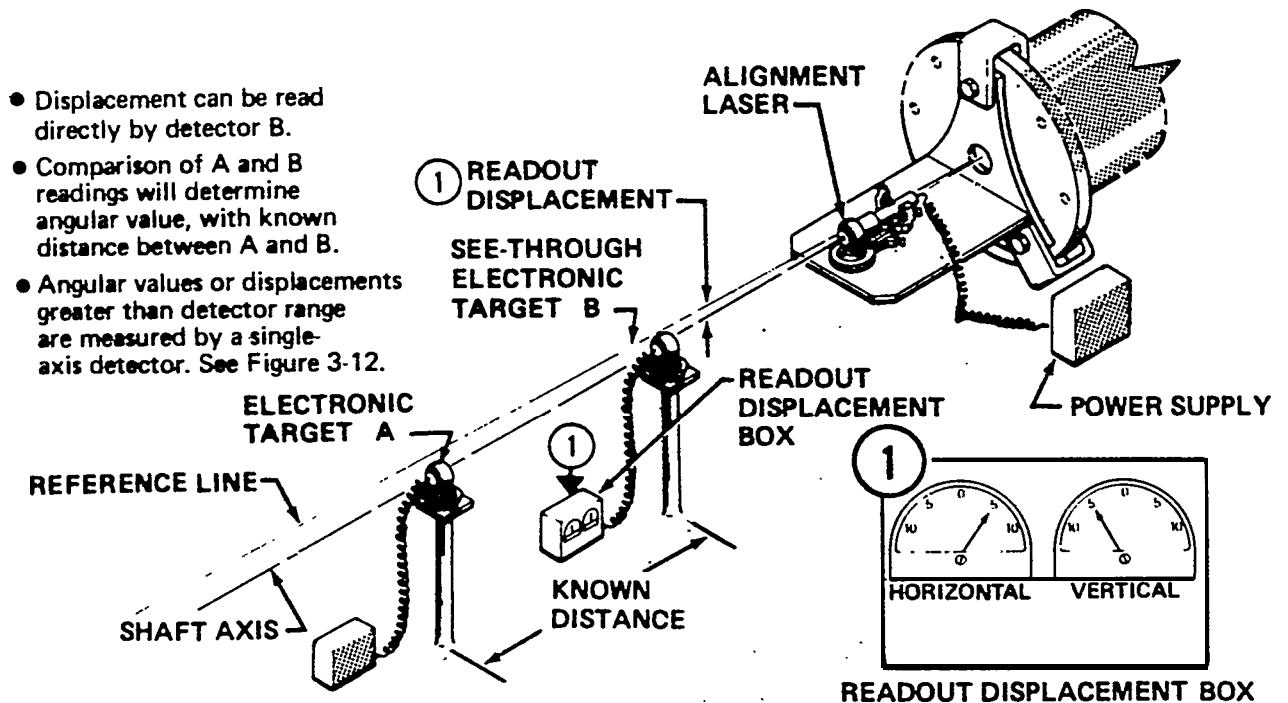
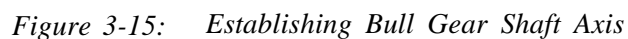


Figure 3-14: Measuring Displacement and Angular Relationships With Solid Propulsion Shaft

This method is illustrated in Figures 3-15 and 3-16. Uniquely, the laser beam is fixed relative to the reduction gear. Figure 3-15 illustrates how to compensate for deflection of the shaft due to the bull gear mass. This is achieved by establishing the reference beam with respect to the shaft centerline only at the center of bull bearing reactions. The entire gear is manipulated until the beam is oriented as required with respect to the two known reference points, A and B, see Figure 3-16.



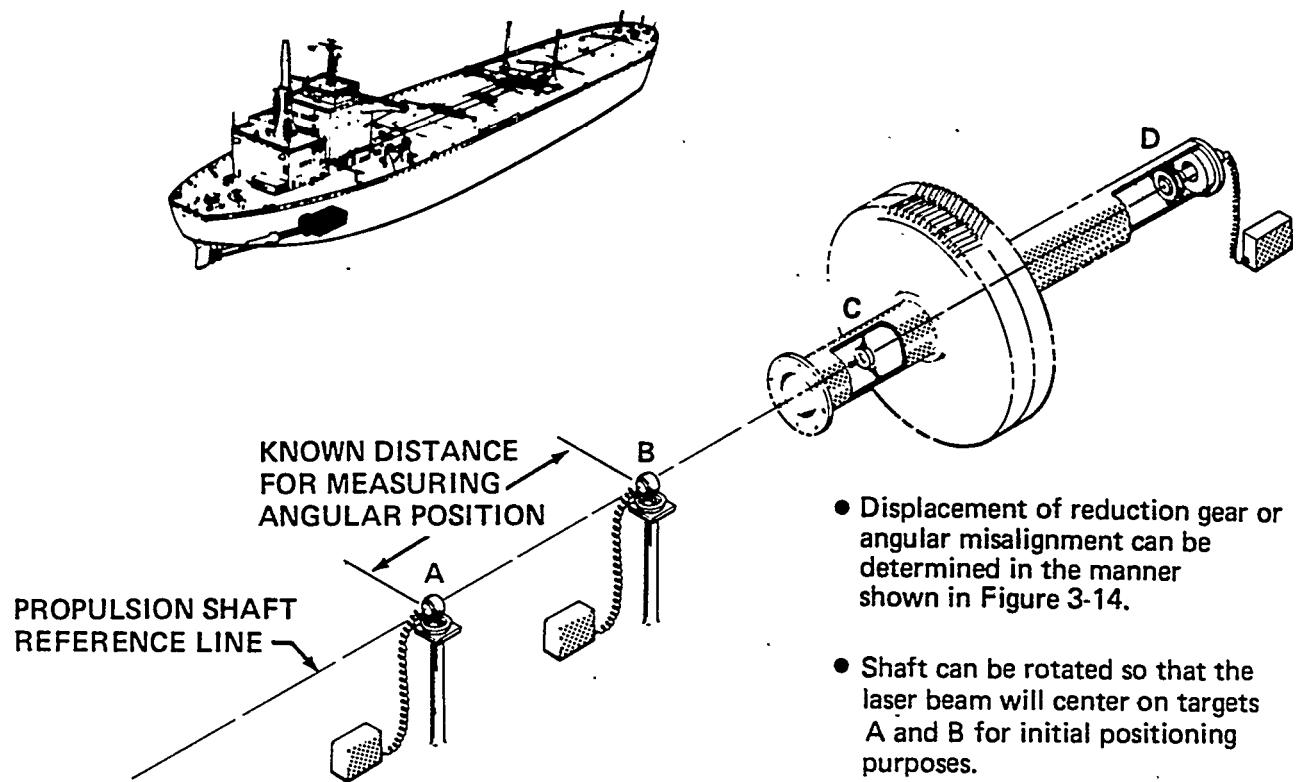
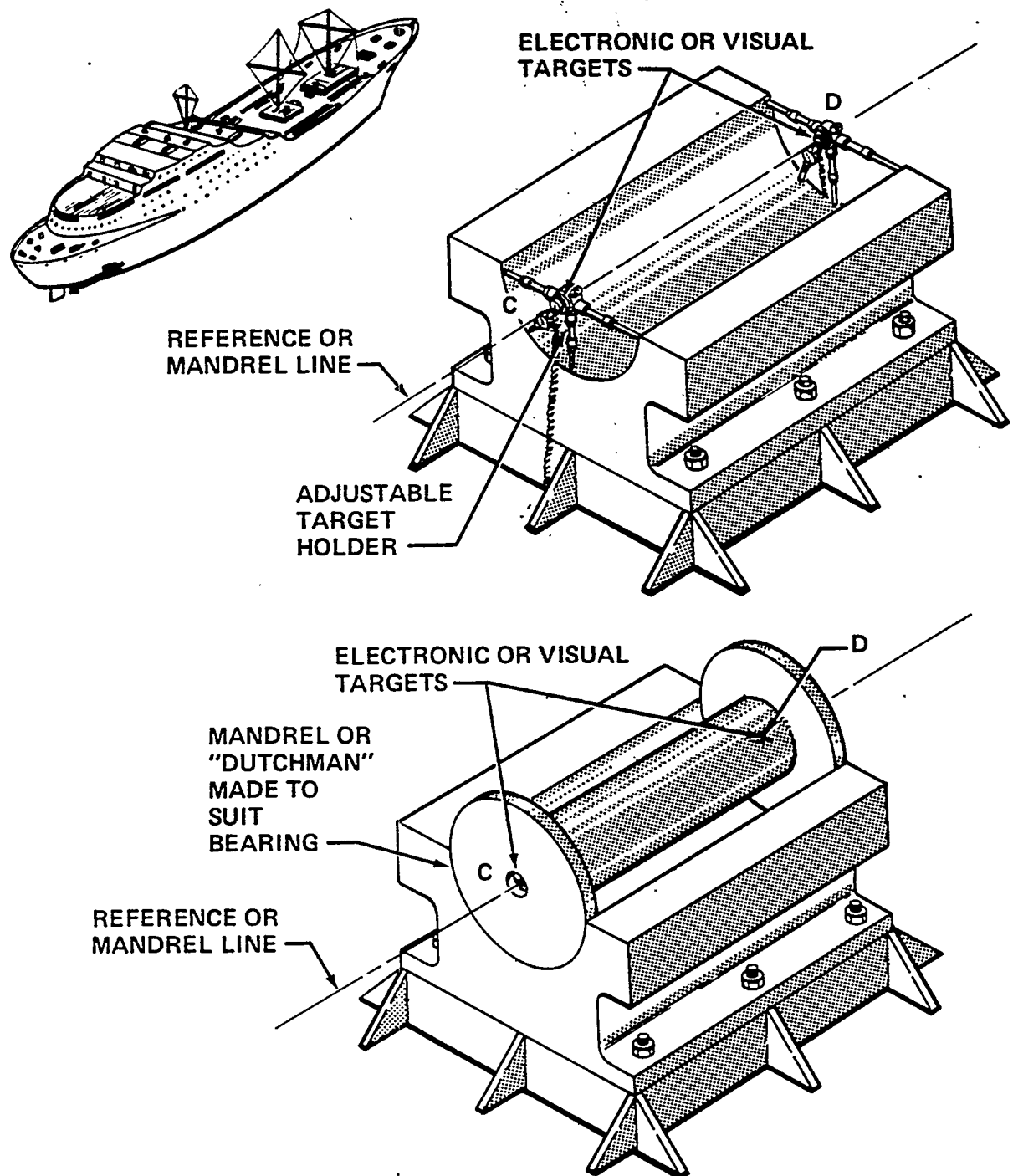


Figure 3-16: Positioning Reduction Gear (Hollow Shaft)

3.1.7 Positioning of Line Shaft Bearings or Temporary Shaft Supports

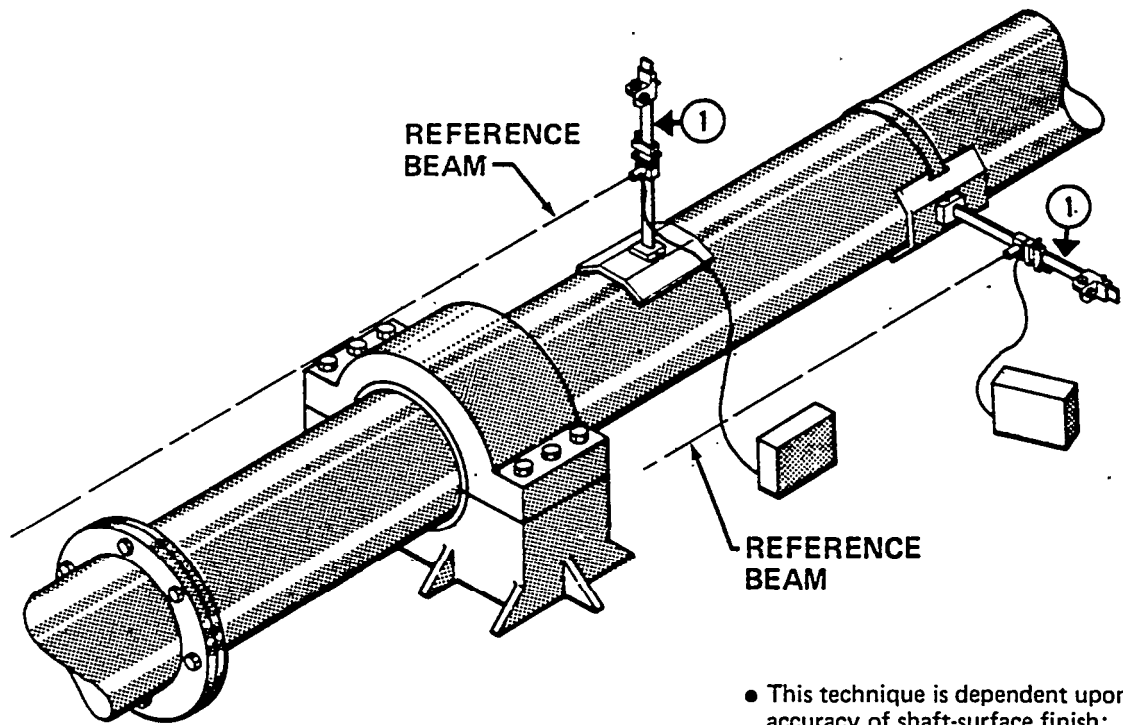
Depending upon the alignment procedures prescribed in a shipyard, the techniques illustrated in Figure 3-17 can be used to achieve initial or final positioning of the line-shaft bearings. Where dependence is placed on final positioning by measuring “sags and gaps” (or “drops and openings”) and/or by actually weighing for determining bearing reactions, the visual targets (Figure 2-1 5) could be used for initial alignment within ± 0.020 inch. With a reasonable degree of skill, they could achieve accuracies of ± 0.005 inch in this application. Use of electronic targets (Figures 2-11.2-12. and 2-13) eliminates all human judgments, and absolute accuracies of ± 0.001 inch are possible.



- Electronic or visual targets can be used.
- Displacement of the bearing or angular orientation from the reference line may be established using the two readout meters.

Figure 3-17: Positioning Line Shaft Bearings or Temporary Shaft Supports

3.1.8 Checking Alignment of Installed Shaft



- This technique is dependent upon accuracy of shaft-surface finish; it could be necessary to limit it to journal areas only.

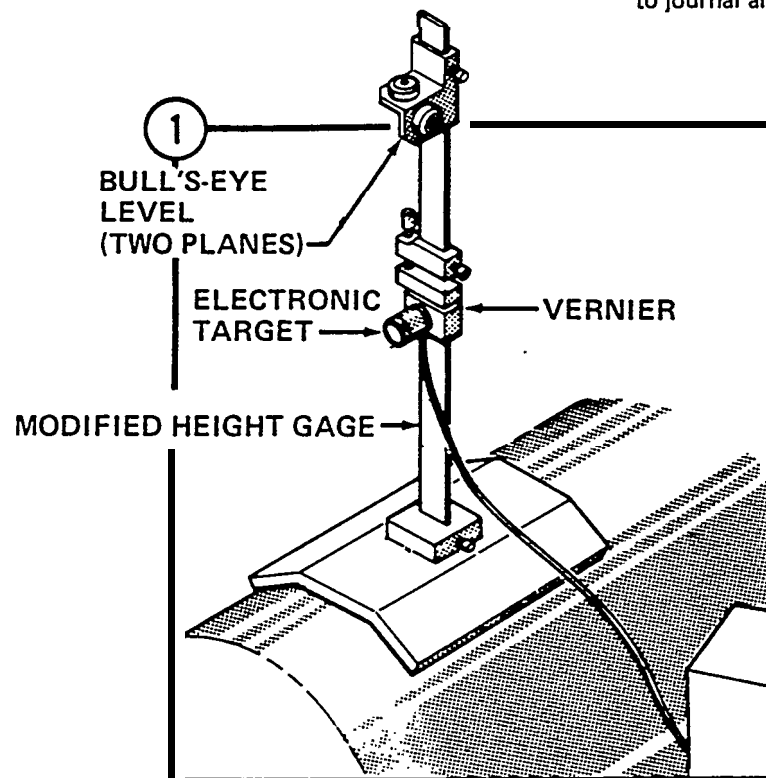


Figure 3-18: Checking Alignment of Installed Shaft

3.1.9 Permanent References for Re-establishing Shaft Alignment

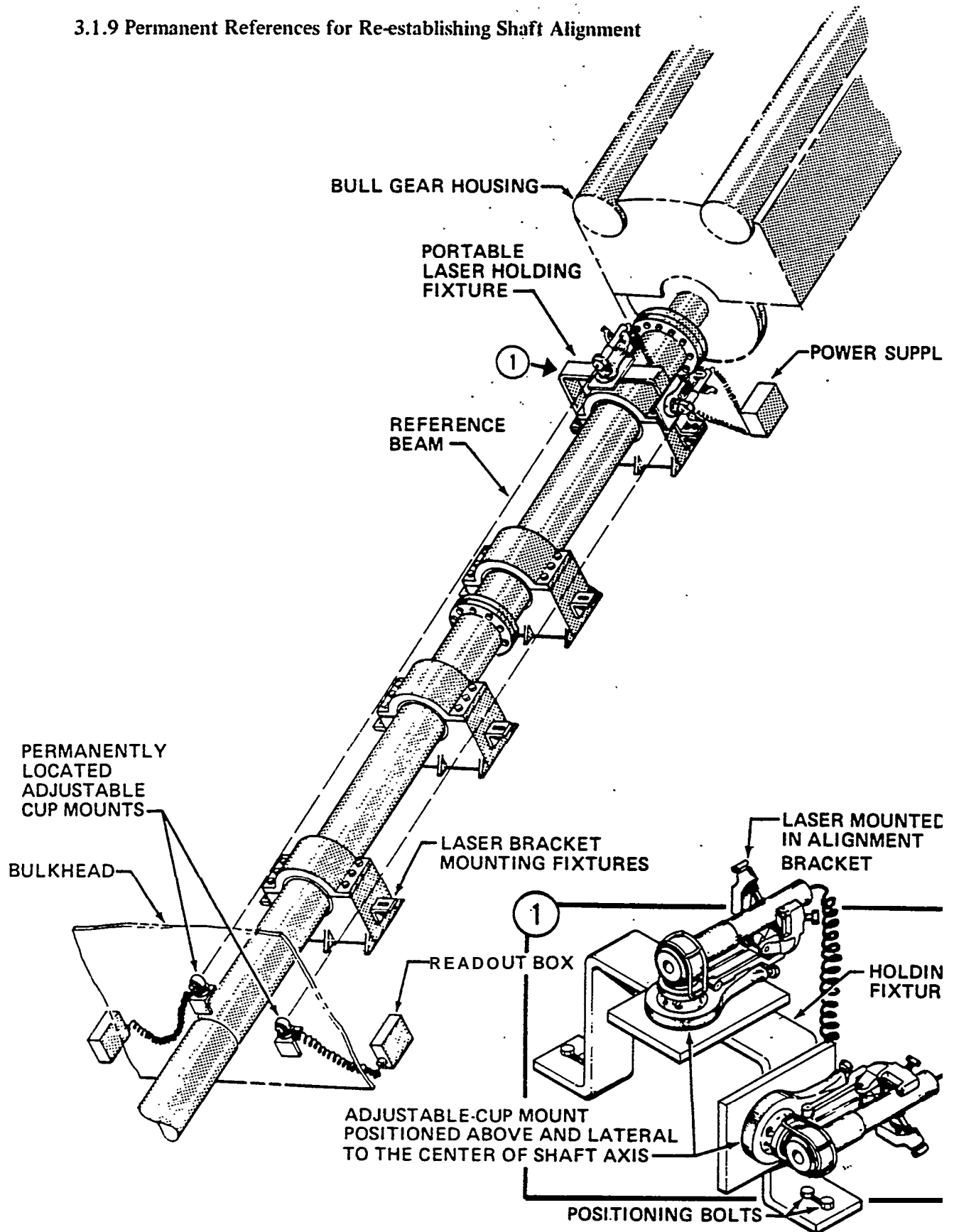


Figure 3-19: Permanent References for Re-establishing Alignment

3.2 PROPULSION SHAFT ALIGNMENT WITH CONVENTIONAL STERN TUBE

3.2.1 Establishing a Reference Line

See Figure 3-20.

3.2.2 Joining Sterntube Erection Unit (or Sterntube if Installed Separately)

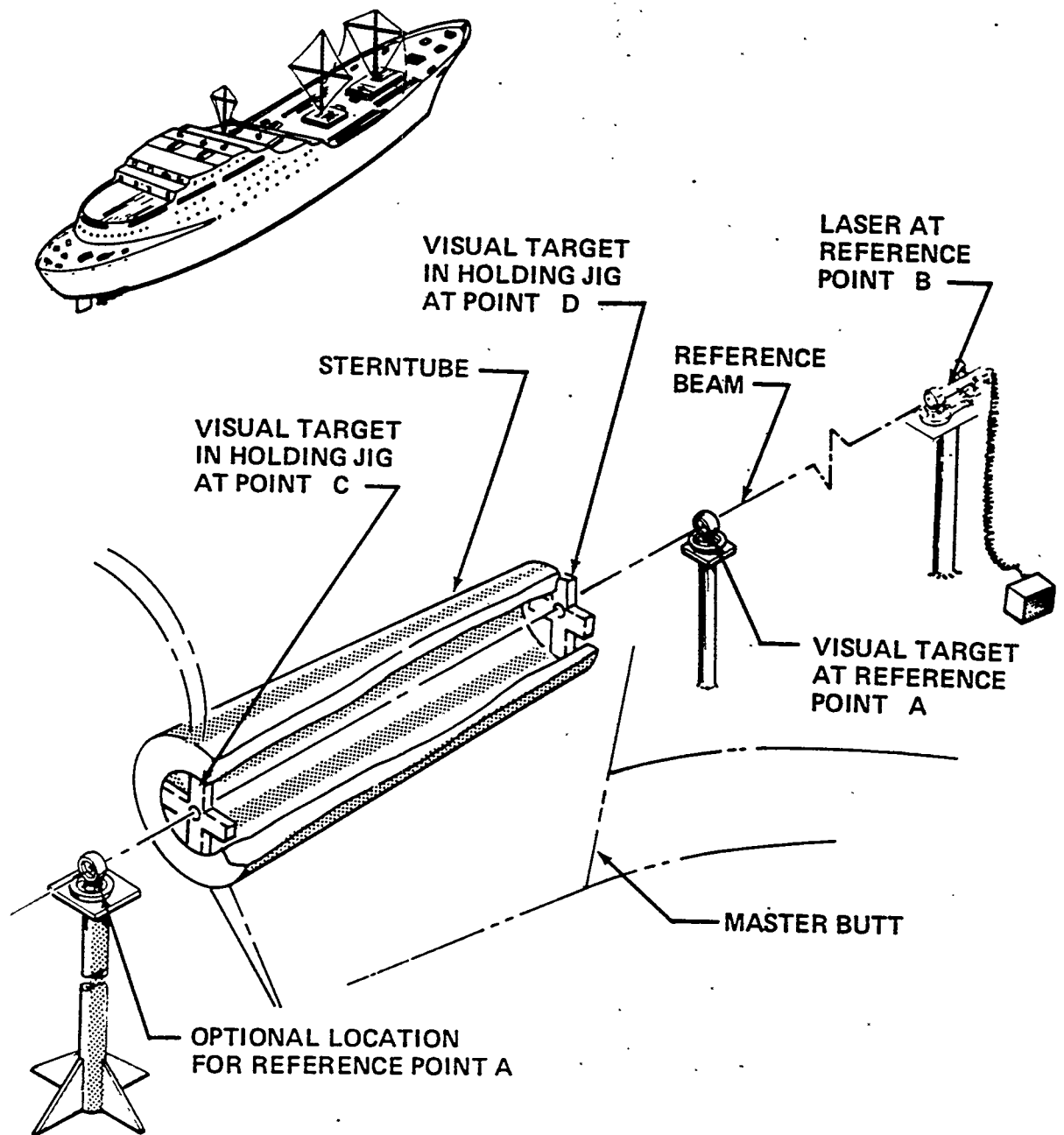
See Figure 3-20.

Visual targets C and D can be installed in the shop:

- On the axis of the sterntube if it is to be installed concentric with reference line AB
- Offset from the axis of the sterntube if the sterntube is to be installed other than concentric to reference line AB.

Visual targets properly designed for the distances they are located from the beam source will readily detect deviations of *1 millimeter (see Appendix C). Normally, both targets can have the same diameter holes if they are within 50 feet of each other.

Visual targets should be observed continually to monitor any movement of sterntube alignment during welding of the erection unit and until completion of all other welding in the vicinity.



- Points A and B define the reference line.
- Points C and D are used to position the sterntube erection unit to the reference line.

Figure 3-20: Establishing a Reference Line for Positioning Erection Unit Containing Sterntube (or Sterntube if Installed Separately)

3.2.3 Re-establishing Propulsion-Shaft Reference Line to Joined Sterntube

The reference line has to be re-established based on the actual position of the sterntube achieved. Depending upon a particular shipyard's procedure, the re-established line will be used either for first boring the sterntube or for first positioning the reduction gear. In both cases, since machinery tolerances are generally 0.005 inch, an alignment laser and electronic targets should be used to establish:

- Reference line for first boring the sterntube. see Figure 3-21.
- Reference line for first positioning the reduction gear (solid shaft), see Figure 3-22.
- Reference line for first positioning the reduction gear (hollow shaft), see Figures 3-23 and 3-24.

3.2.4 Aligning Reduction Gear, Positioning Line Shaft Bearings. and Checking Alignment of Installed Shaft and Permanent References for Re-establishing Shaft Alignment

See Sections 3.1.5 through 3.1.9 and Figures 3-3 through 3-19, respectively.

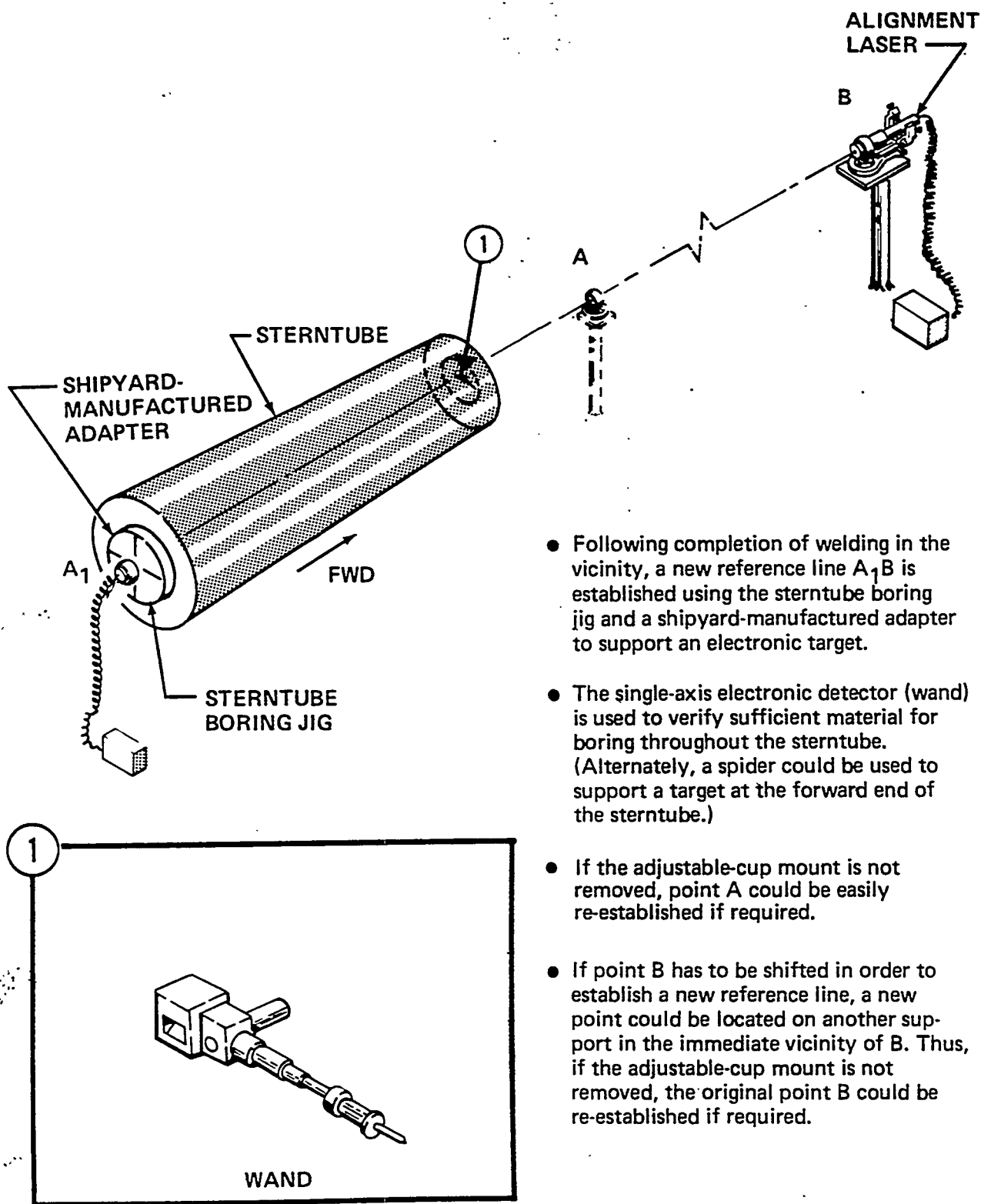


Figure 3-21: Establishing a Reference Line for First Boring Sterntube

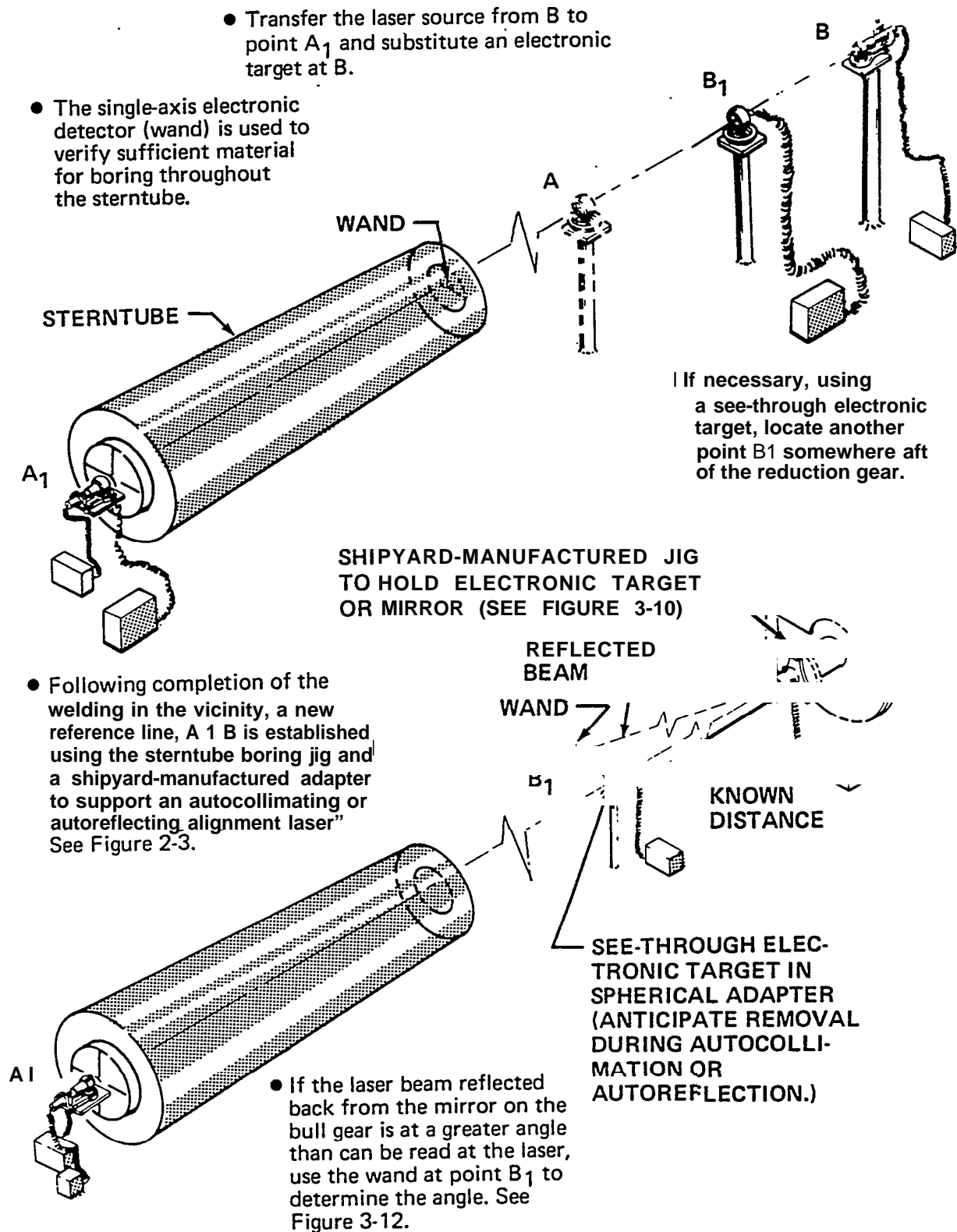


Figure 3-22: Establishing a Reference Line First Positioning Reduction Gear (Solid Shaft)

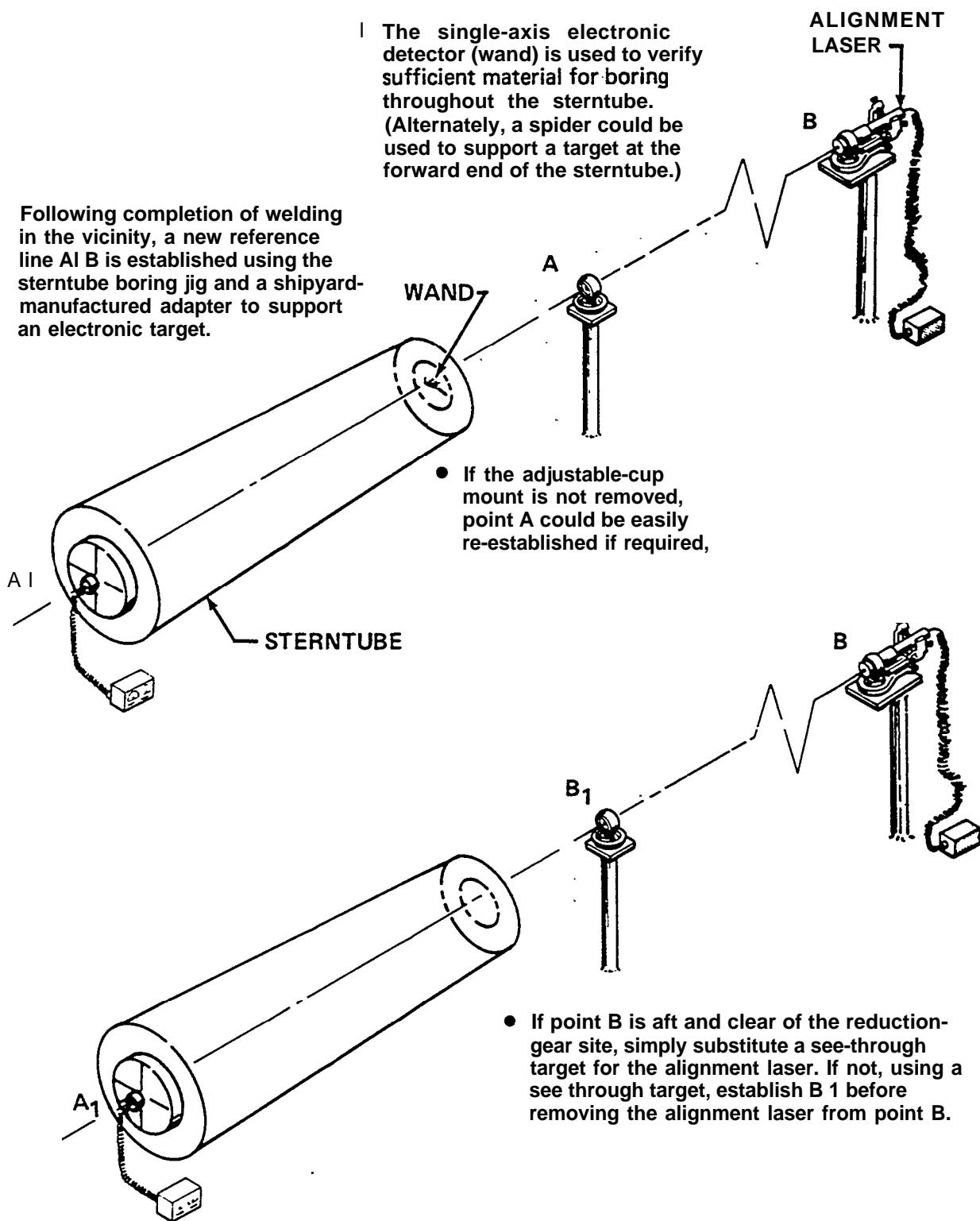


Figure 3-23: Establishing a Reference Line for First Positioning Reduction Gear (Hollow Shaft)

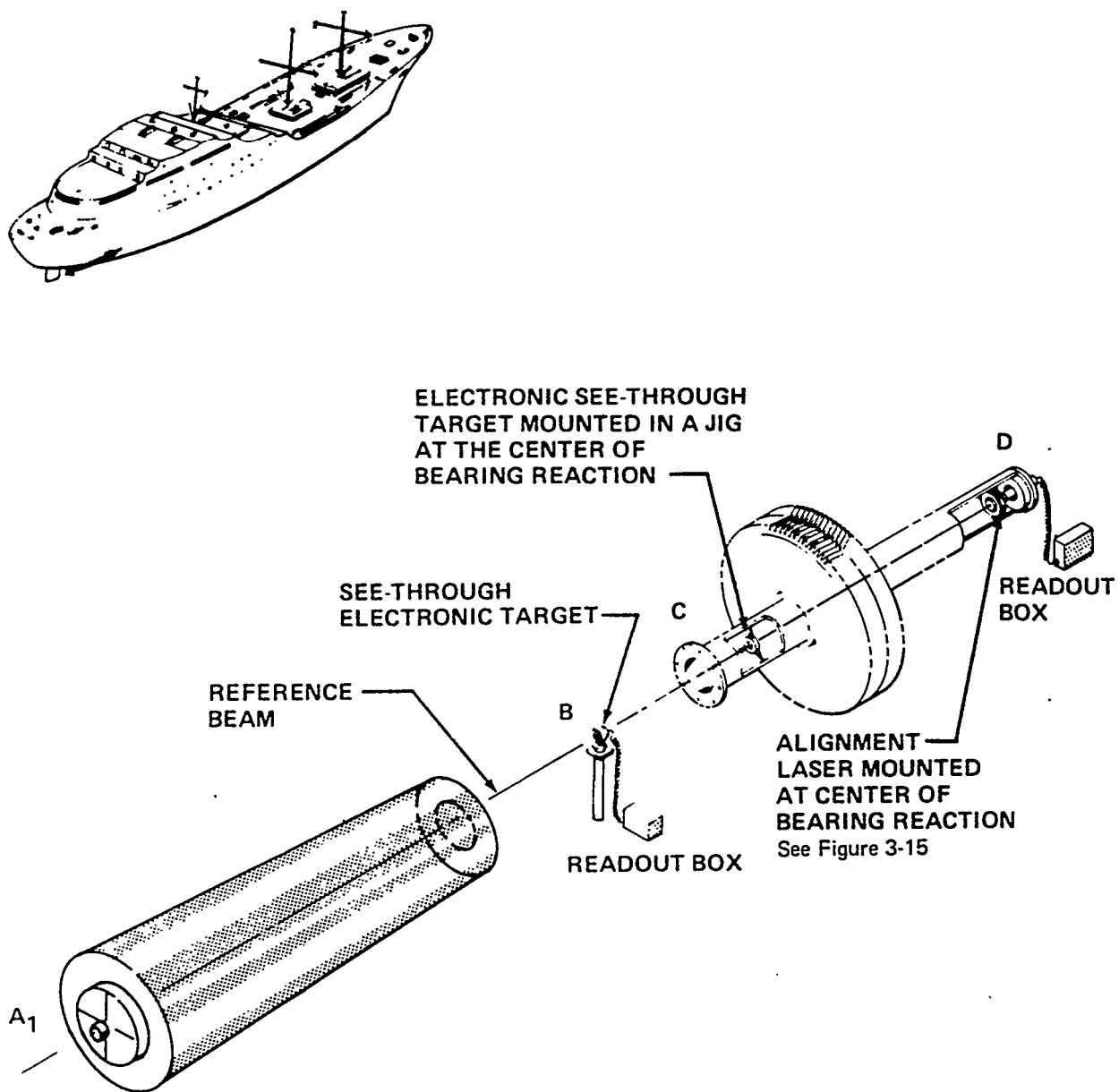


Figure 3-24: Establishing a Reference Line First Positioning Reduction Gear (Hollo Shaft)

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3.3 ALIGNMENT FOR INSTALLATION OF LARGE RUDDERS AND RUDDER STOCKS

3.3.1 Positioning Rudder

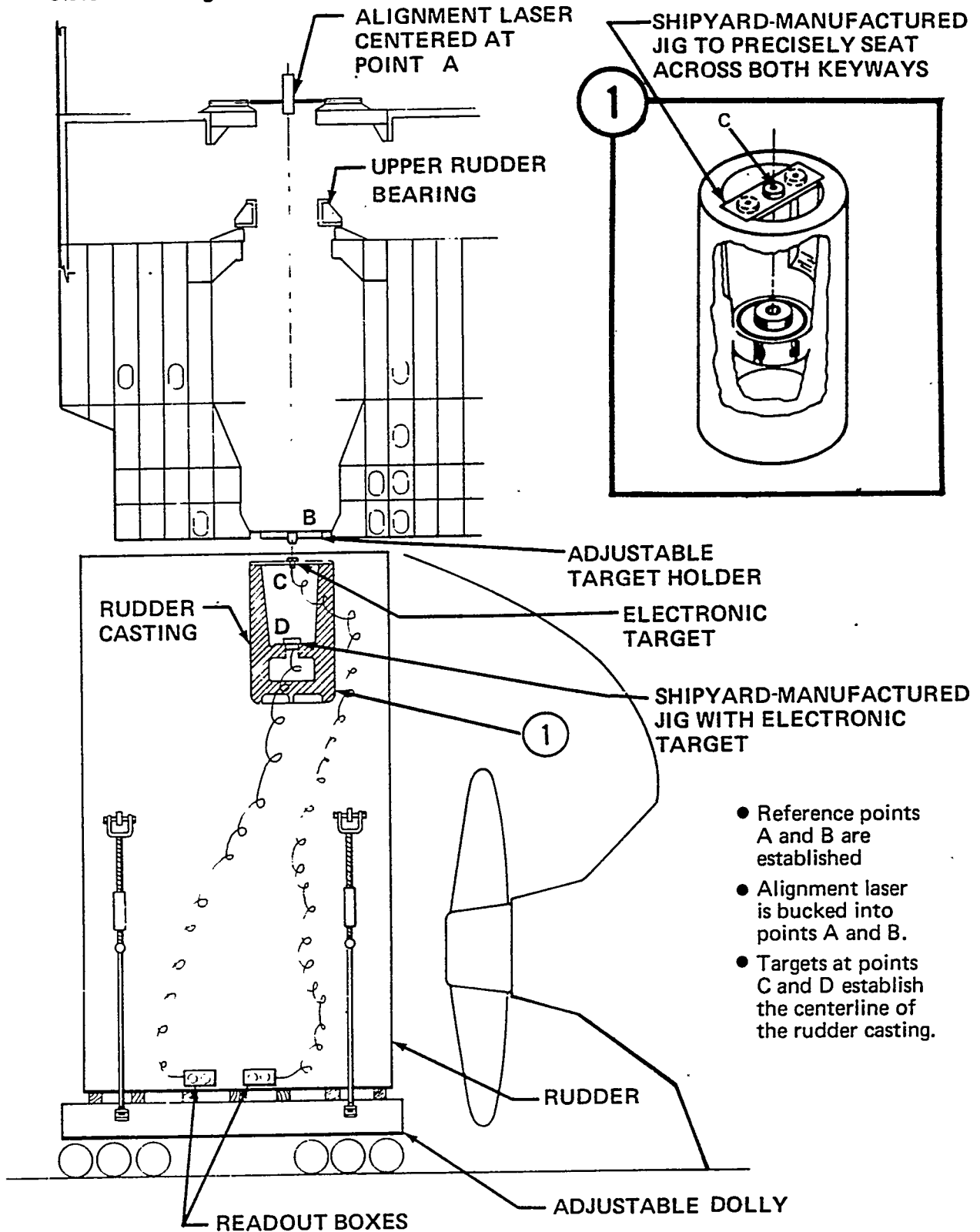
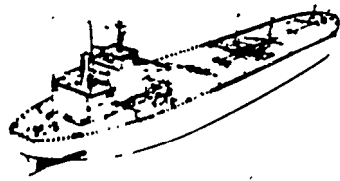


Figure 3-25: Positioning the Rudder, (based upon an actual application).

3.3.2 Aligning Rudder-Stock Keys to Keyways in Rudder Casting



- Without disturbing the location of the alignment laser used for positioning the rudder (Figure 3-25), attach a planing prism (Figure 2 22).
- Rotating the planing prism housing and sweeping the beam back and forth across the targets spanning point C will establish the plane that bisects the two opposite keyways in the rudder casting.
- Marks denoting this plane are easily established on the surrounding structure and can be used as guides when lowering the rudder stock with the keyways attached.

See Enlarged View
in Figure 3-25

1

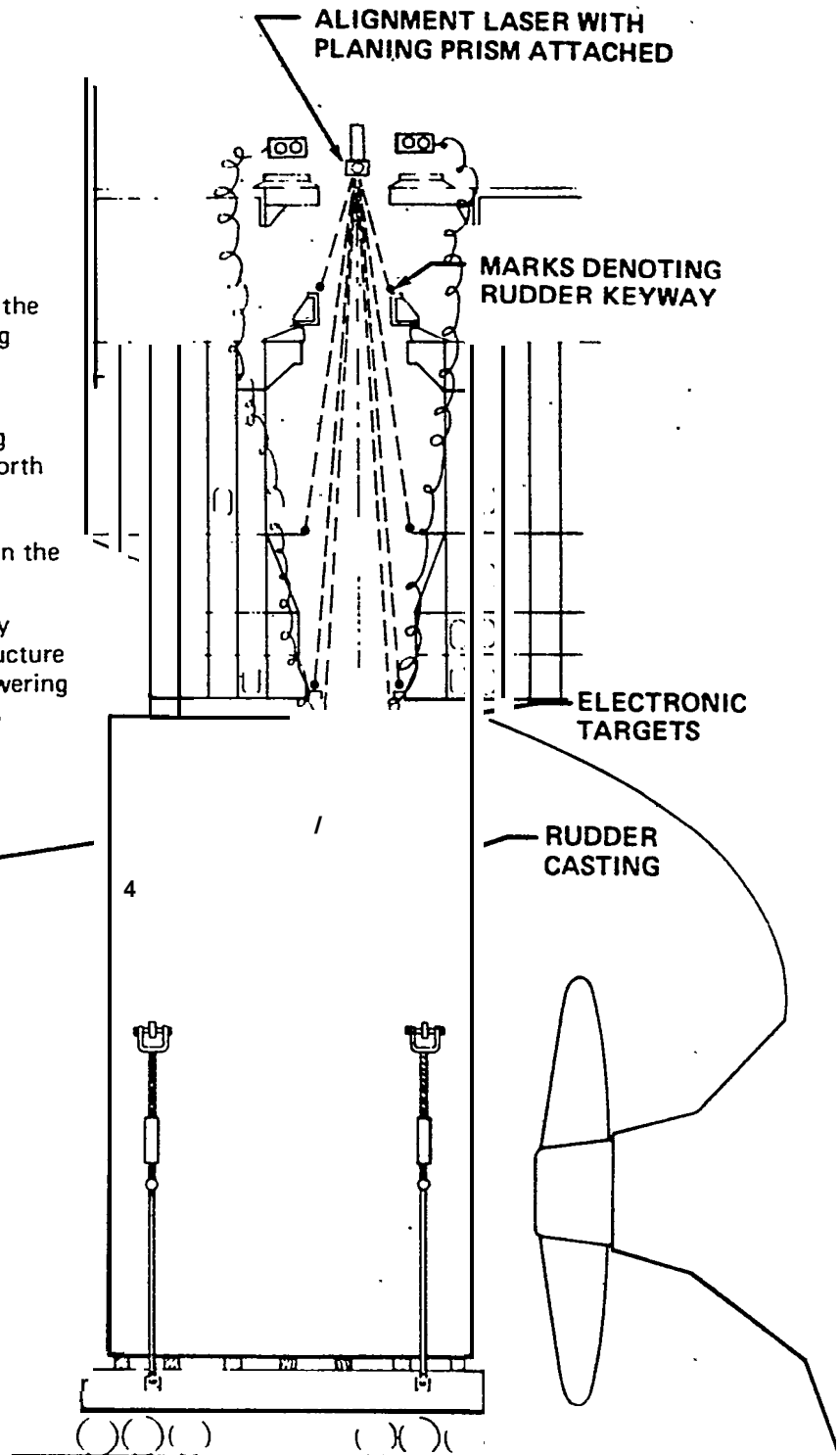


Figure 3-26: Aligning Rudder Stock Keys to Keyways in Rudder Casting
(based upon an actual application).

3.4 HULL STRUCTURE ALIGNMENT

3.4.1 General

For hull structure, lasers would only be more productive than conventional optics when:

- Two or more people need access to the reference beam at the same time.
- An object has to be positioned with respect to a fixed reference line.
- Establishing a plane or measuring deviations from a reference plane or reference line.
- The reference line must pass through small openings.
- There are poor ambient lighting conditions.
- The reference line has to be redirected as with a prism or mirror and the mirror or prism is remote from the instrument.
- Using the beam as a pointer to position “punch” marks.

3.4.2 Practical Ranges

Since much of the hull structure alignment would take place in daylight, it should be clearly understood that:

- With a decrease in lighting due to shadows or on-coming darkness, it becomes more difficult to sight optically. whereas sighting with a laser becomes less difficult.
- With increasing ambient brightness, the optical sighting will improve and the following range limits will be imposed on practical use of existing lasers due to the imposed 1-milliwatt limitation by OSHA as of 1973.
 - 100 feet with the observer located at laser source
 - 600 feet with the observer located at the target site.

3.4.3 Typical Hull Structure Alignment Tasks

3.4.3.1 Establishing Base Plane and Keel Reference Line

See Figures 3-27, 3-28, and 3-29.

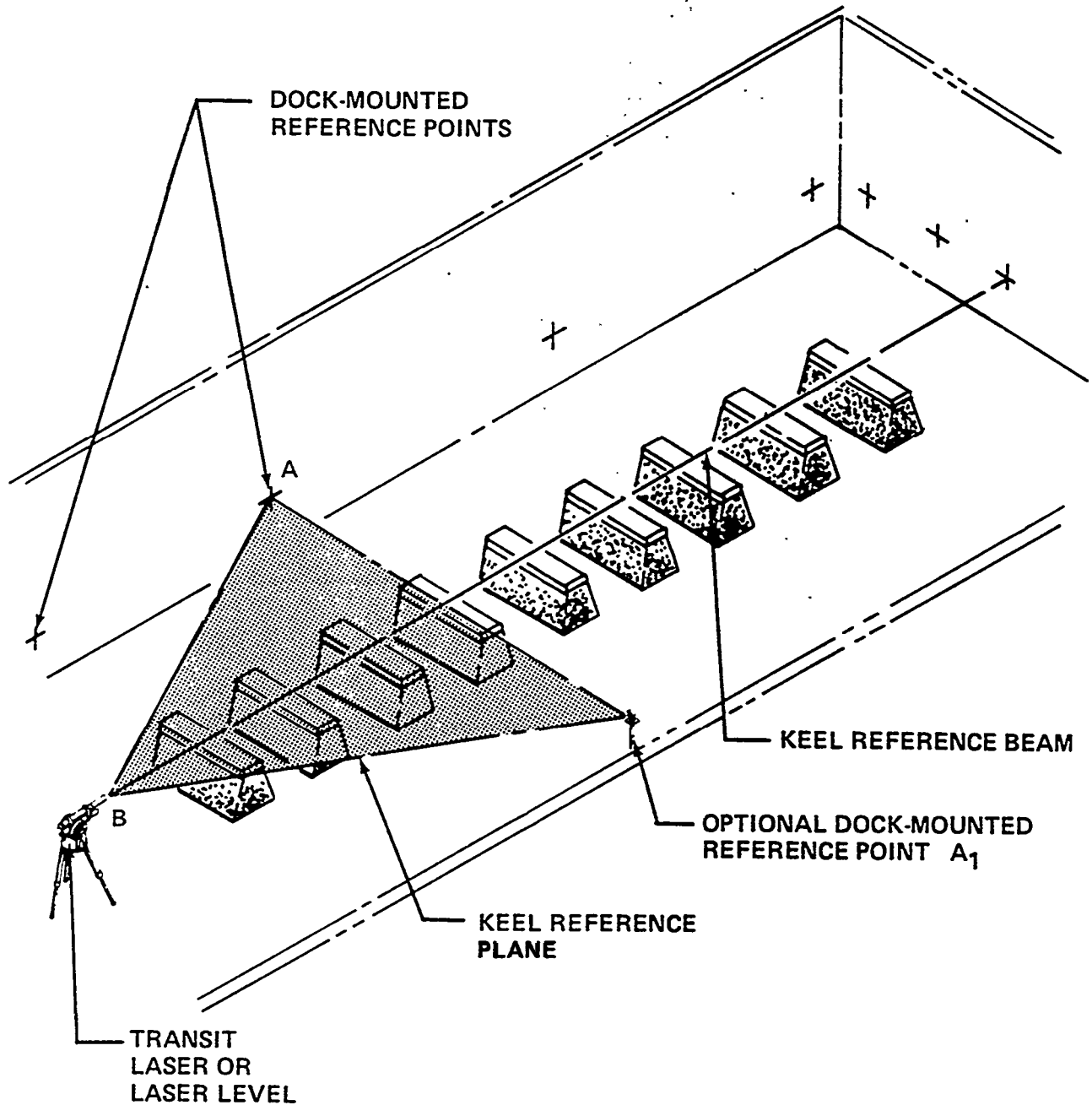


Figure 3-27: Establishing Keel Reference Plane and Line

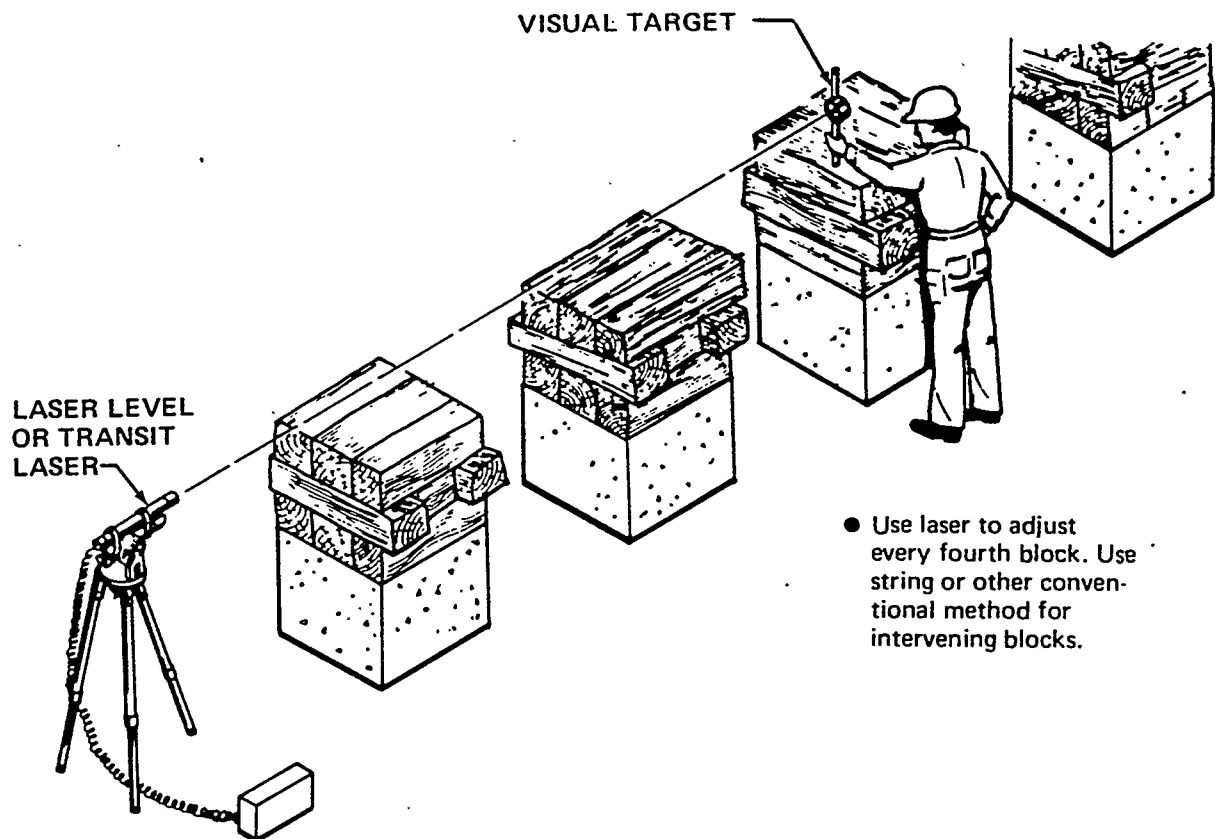


Figure 3-28: Adjusting the Height of Keel Block Into Keel Plane

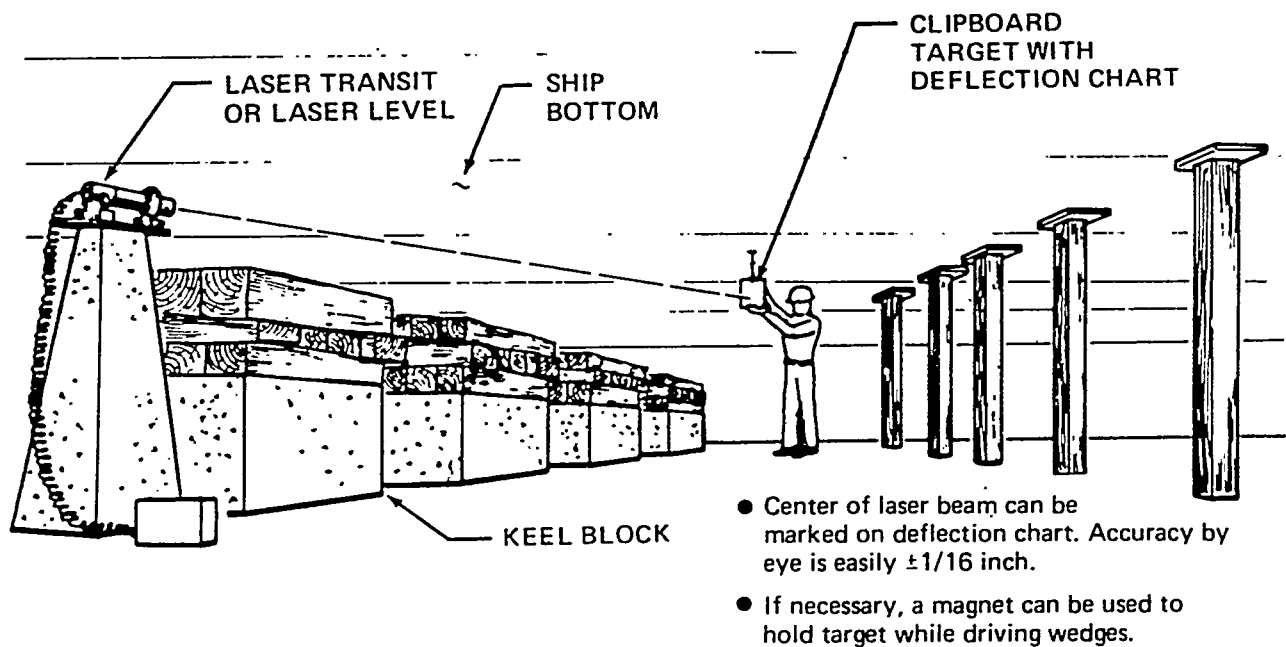


Figure 3-29: Measuring From Bottom of Ship to Check Levelness or Proper Declivity Angle

3.4.3.2 Controlling Dimensions in Subassembly Fabrication: See Figures 3-30 and 3-31

1 A tooling dock used for aircraft manufacture and already applied to shipbuilding in Japan, facilitates the assembly of hull modules. The dock provides access to locations that are best for alignment purposes.

Necessarily, the dock structure must be stiffened commensurate with the accuracy required. It may be rather elaborate as illustrated in Figure 3-30 or it could simply consist of 4-poles. The interior structure of a building could serve provided it does not deflect during crane movements.

The dock structure could also serve to contain ladders and staging for access to the module, a folding or sliding roof, power units for welding, lighting, etc.

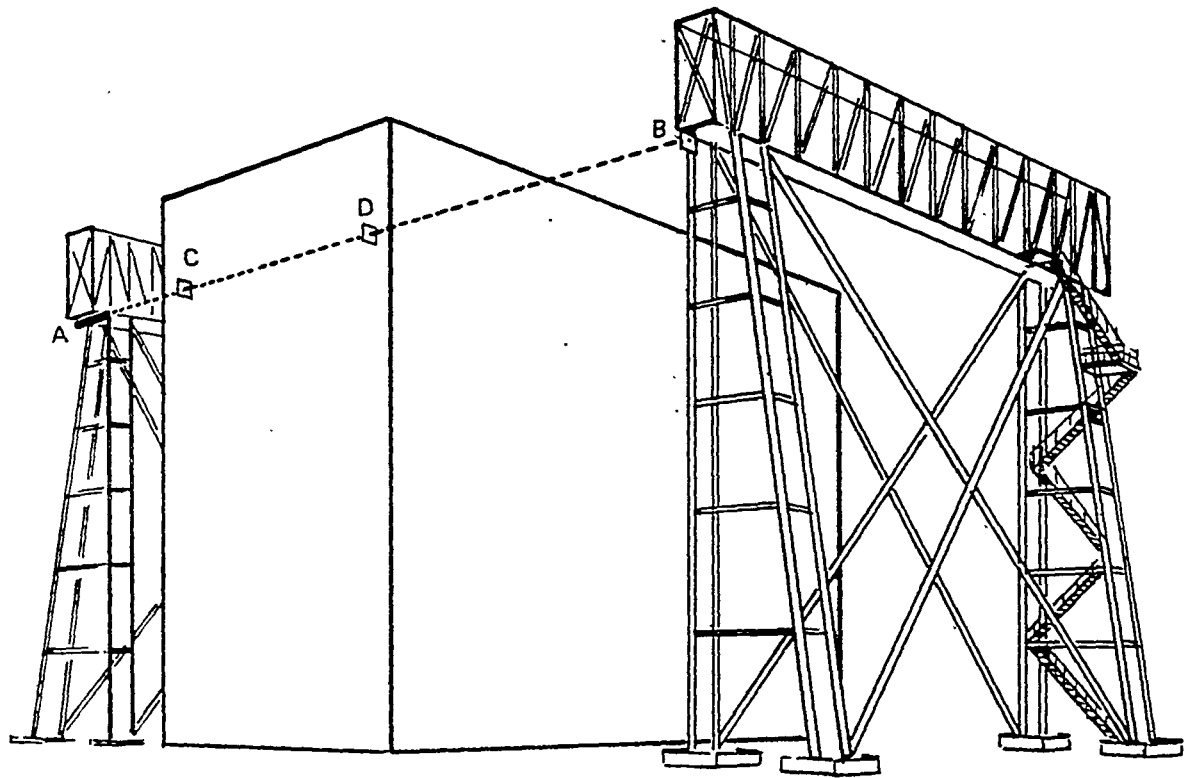
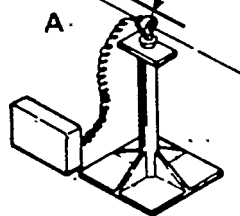


Figure 3-30: Applying a Tooling Dock

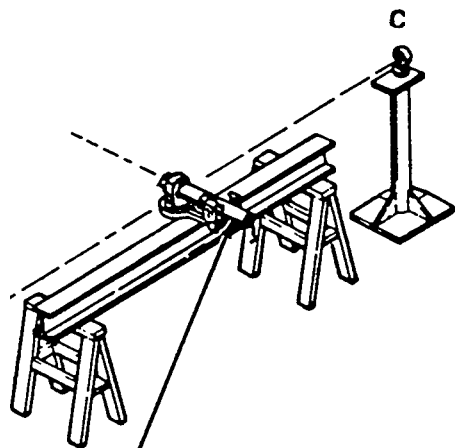
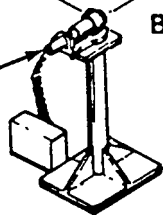
- Simple laser establishes reference line through visual targets at A & B.
- Erection unit is aligned to reference line using visual targets at C & D, the process is repeated elsewhere as required.

ELECTRONIC TARGET
IN SPHERICAL
ADAPTER

WORK AREA FOR STEEL
FABRICATION, PIPING
SUBASSEMBLY, ETC.



AUTOCOLLIMATING OR
AUTOREFLECTING
ALIGNMENT LASER

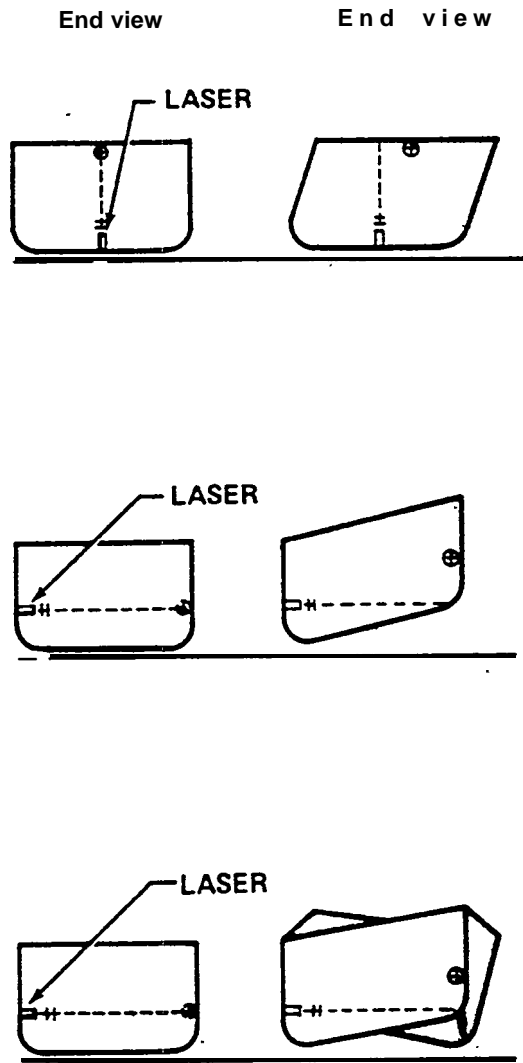


AUTOCOLLIMATING
OR AUTOREFLECTING
LASER WITH PLANING
PRISM

Figure 3-31: Portable Tooling Dock precise Subassembly Fabrication

3.4.3.3 Providing Reference Lines and Planes Before Modules Are Removed From Erection Sites

See Figures 3-32, 3-33, and 3-34.



- Three reference points are required; See Figure 3-33.

Figure .3-32: Providing Reference Lines to Monitor Racking and Twisting

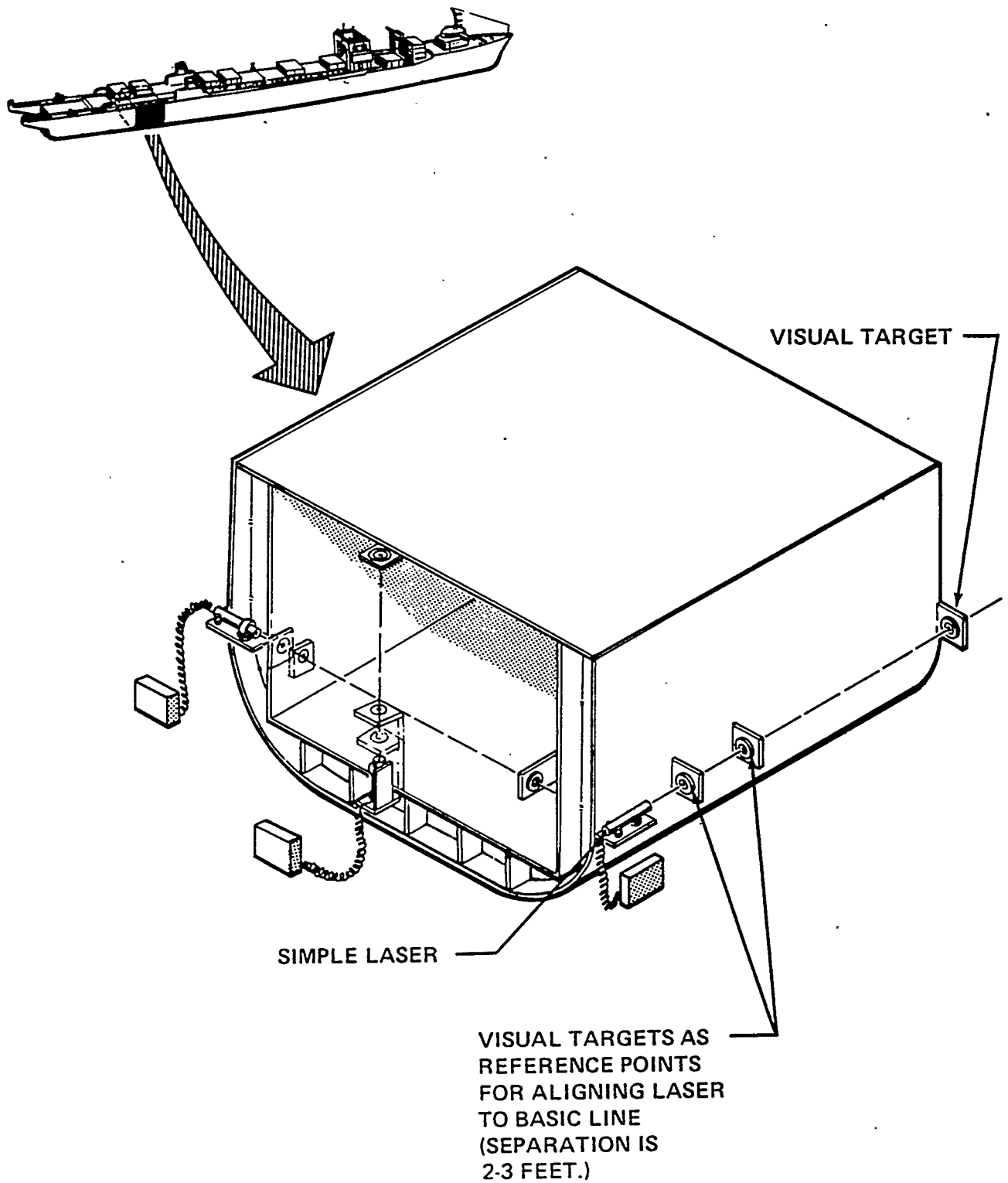


Figure 3-33: Providing Reference Lines on Modules When They Are Moved From Fabrication to Launch Sites

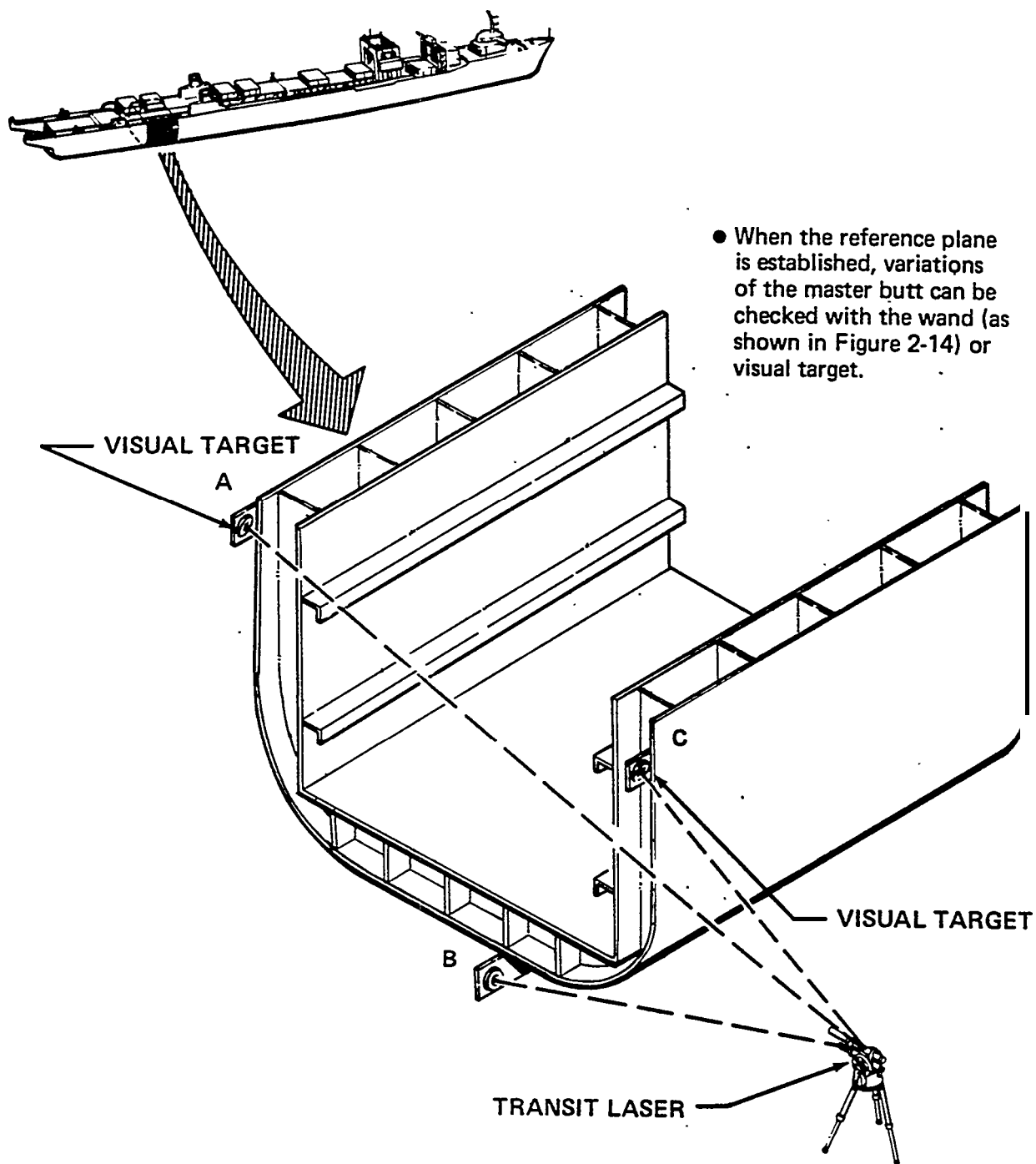


Figure 3-34: Checking Master Butt for Variations From Vertical Plane

3.4.3.4 Positioning Container Guides

A technique for aligning container guides parallel to each other and perpendicular to a common base plane is illustrated in Figures 3-35, 3-36, and 3-37.

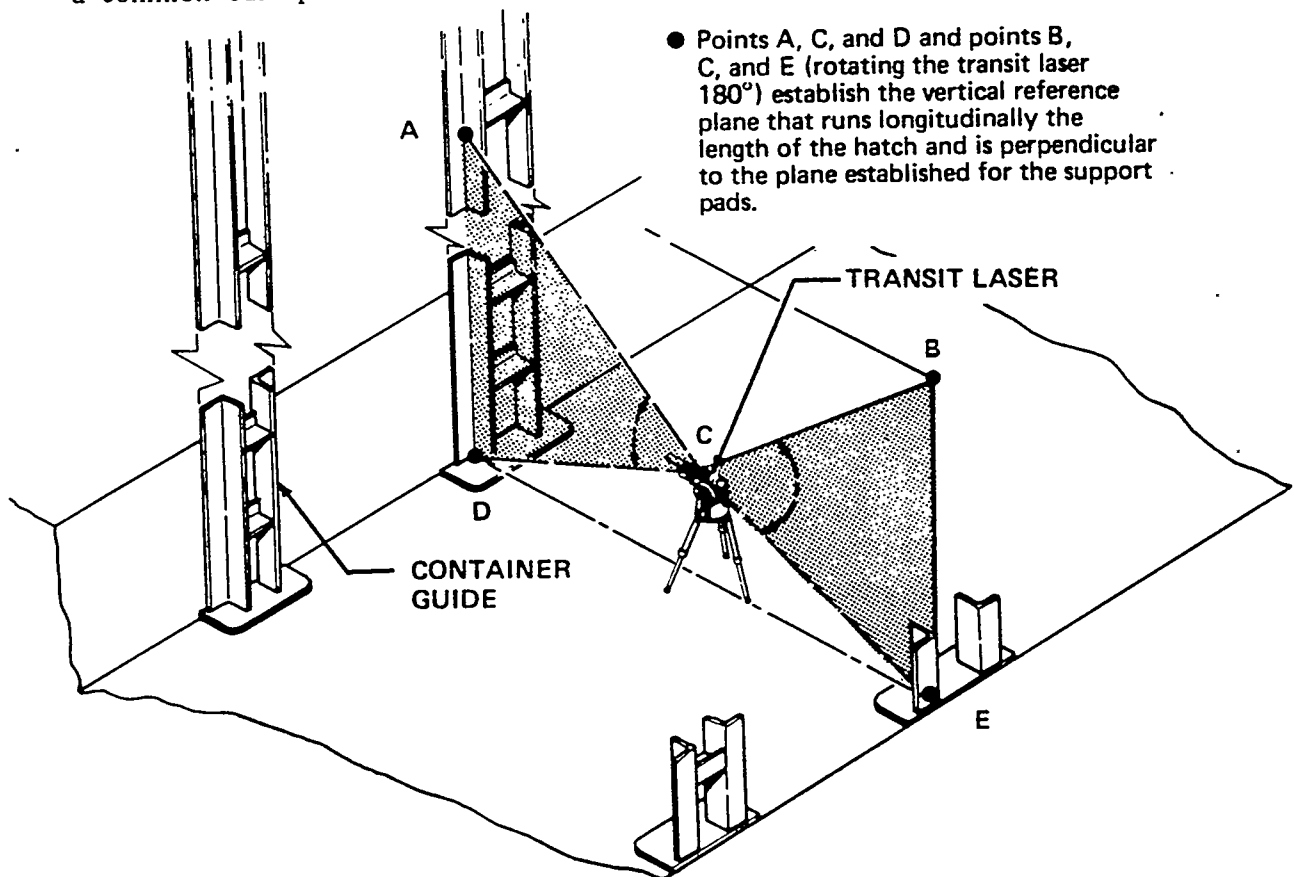


Figure 3-35: Establishing Vertical Plane for Positioning Container Guides

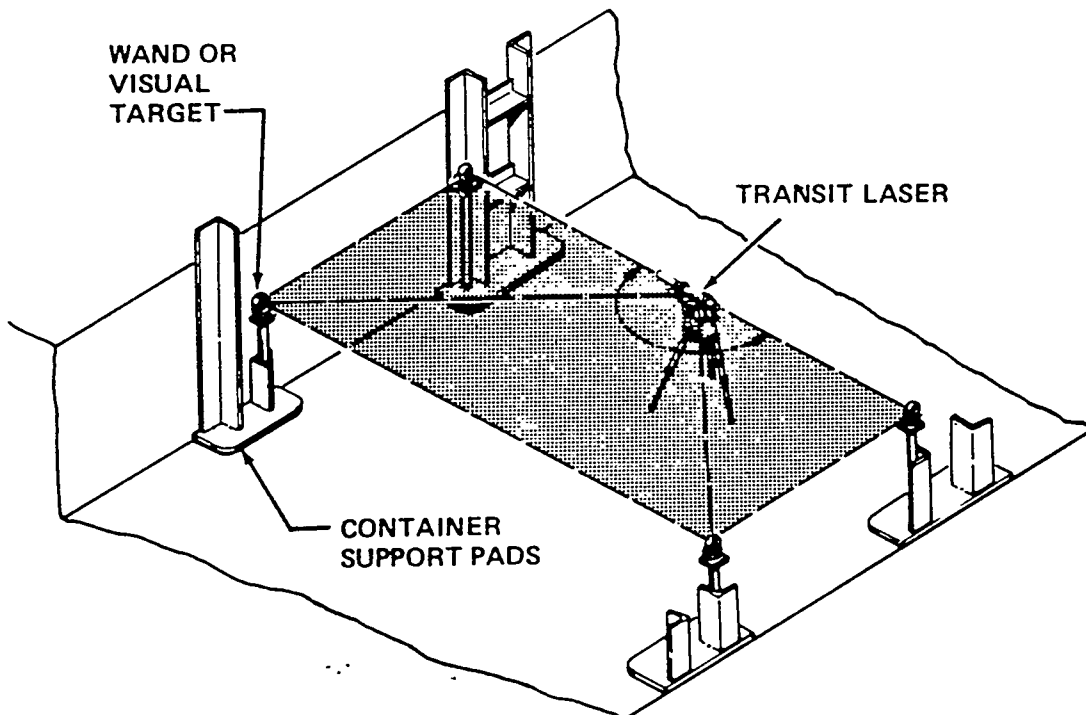
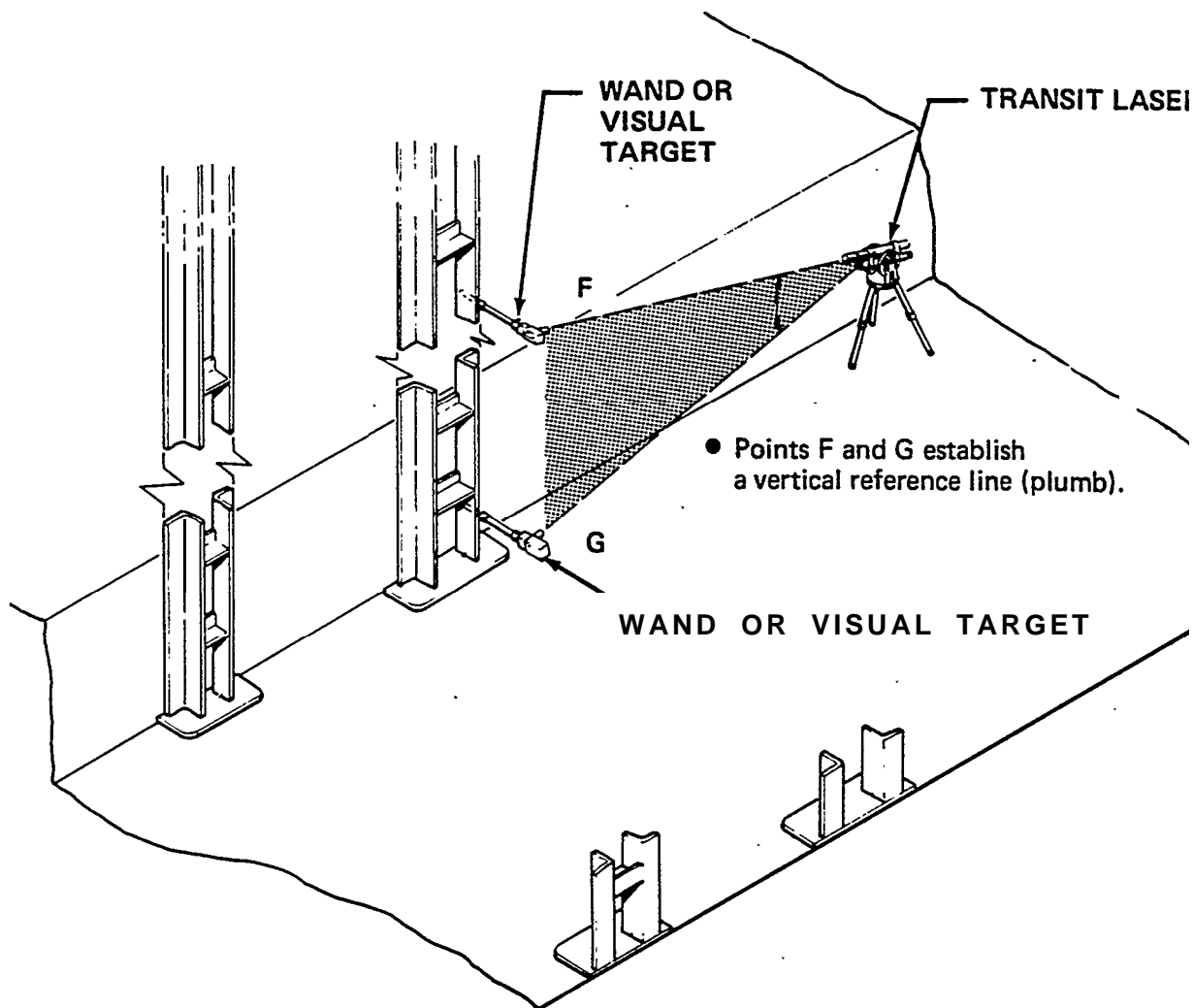


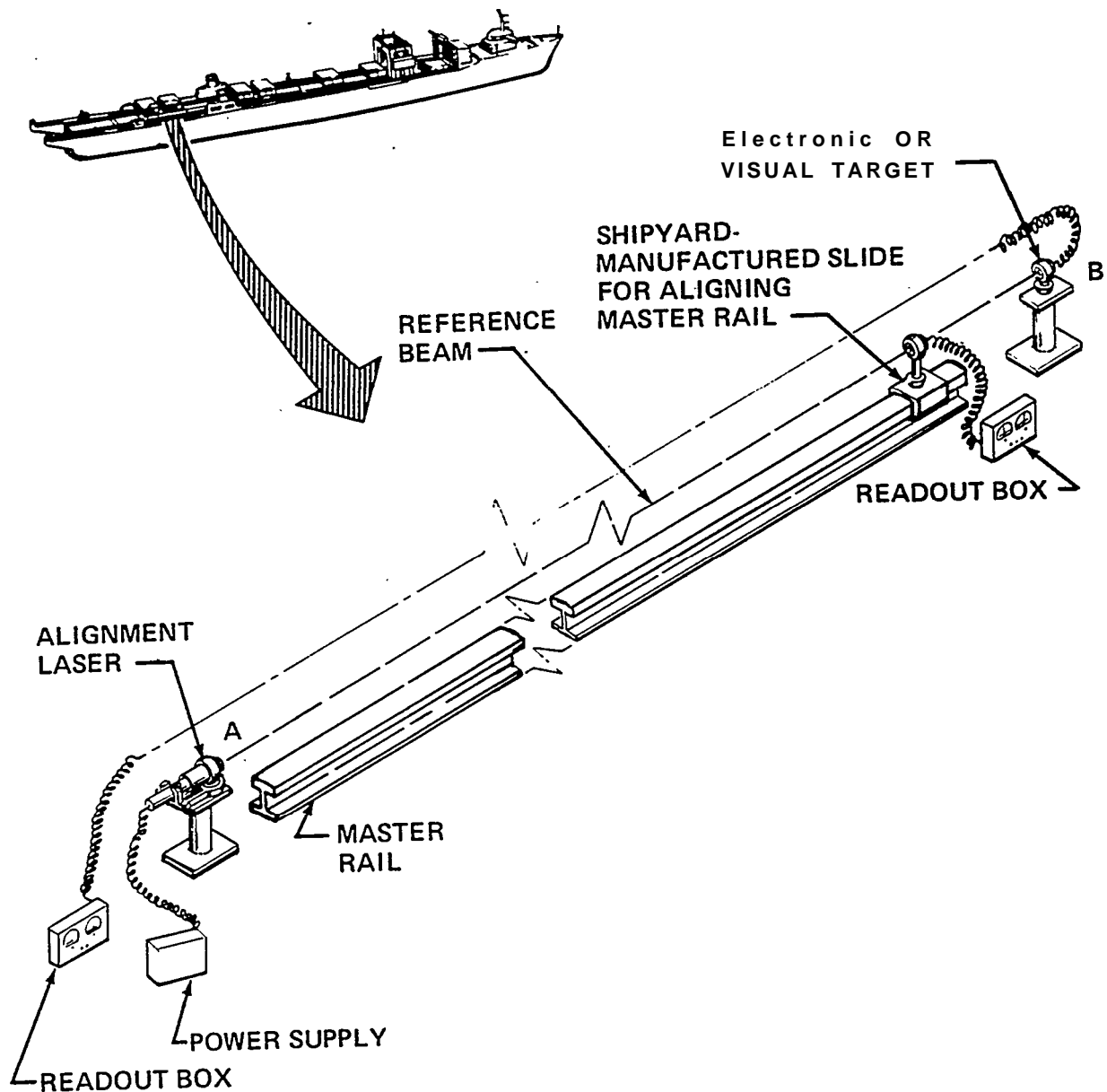
Figure 3-36: Establishing Plane of Container Support Pads



- For nonlevel ships, reference points must be established from the surrounding structure. The planing prism and the alignment laser are used to establish the reference lines and planes from these points. The same setups as shown in Figures 3-35, and 3-36 can be used.
- A shipyard-manufactured device, such as shown in Figure 2-40, could be used in this application also.

Figure 3-37: Establishing Plumb Reference Line for Positioning Container Guides

3.4.3.5 Aligning 'Relatively Long Horizontal Rails



- Points A and B define the rail reference line.
- A simple laser can be substituted for the alignment laser and visual targets for the electronic targets in cases where $\pm 1/16$ -inch accuracy over 200 feet is adequate. With the alignment laser, accuracy of ± 0.010 inch is possible over 200 feet.

Figure 3-38: Aligning Relatively Long Rails

3.5 IDEAS FOR OUTFITTING APPLICATIONS

- 1) Reference lines are more easily transferred throughout the interior structure as the ship is erected because the laser beam:
 - Is visible in most interior lighting conditions
 - Is readily bent with prisms
 - Establishes a visible reference point when intercepted by a bulkhead or deck.

The transit laser would be used in place of a transit telescope.

- 2) Striking waterlines on concave surfaces, such as a flared bow, is facilitated. This requires establishing a laser level at a specified elevation at an approximate radius that is representative of the concave surface.
- 3) Reference lines can be readily placed in the precise location of a piping run or of some other distributive system. Should it become necessary to locate penetrations in beams offset from this reference line, a single-axis detector (wand) or shipyard-manufactured visual wand or gage could be used to establish a parallel reference line. In this application, the intercept of the beam by bulkheads and decks establishes the locations for this penetration. The simple laser, mounted in any method described in this manual, could be used.
- 4) False decks, false ceilings, and grounds for bulkhead sheathing can be done in a manner similar to that described for finishing a reduction gear foundation neat (Figure 3-5) or for establishing the bottom plane for a container ship guide installation, Figures 3-36 and 3-37. A simple laser could be adapted to this use by adding a shipyard-manufactured jig similar to the one in Figure 2-36, provided it is equipped with a spirit level. The transit laser is, of course, ideal to use in these applications. The laser level would be limited to horizontal planes such as for false decks and ceilings.
- 5) The simple laser equipped with a fan beam lens (Figure 2-27) can be used to establish a reference plane that would facilitate detecting warp in structure prior to installation of relatively large doors, windows, and hatches.
- 6) The simple laser can readily substitute for a “piano” wire when establishing reference lines for layout of food service equipment, windows, ports, furniture, etc.

APPENDIX A

LASER SAFETY

As of mid-1973, a proposed safety standard for laser use is being considered by the Department of Health, Education, and Welfare Industry Advisory Committee. The proposed standard lists four classes of lasers as follows:

- Class I: Lasers with a power output of less than a microwatt would be exempt from the standard.
- Class II: Lasers in this class could emit no more than 1 milliwatt power output. This class would not be considered dangerous but would have to carry a label cautioning the users not to stare at the laser beam.
- Classes III and IV: These two classes would include all lasers in excess of 1 milliwatt of power. Class III would be considered potentially hazardous to the eye, and Class IV would be considered hazardous to the skin. Class III and IV devices would have to be shielded from the human eye. They also could not be used for such purposes as demonstrations, surveying, leveling, or alignment.

Lasers to be used for alignment purposes are assigned to Class II. Thus, they cannot emit power exceeding 1 milliwatt.

Since OSHA has established 1 milliwatt per square centimeter as the maximum permissible exposure of continuous laser radiation on the eye, the minimum allowed laser beam diameter is related to the power emitted. For a maximum 1-milliwatt power laser, the beam diameter cannot be less than 1.125 millimeters, which corresponds to an area of 1 square centimeter. *Laser devices built to this maximum power density cannot legally be collimated to a smaller diameter.*

Precautions that should be observed when using a Class II for alignment purposes are:

- Post areas with adequate caution signs.
- Ensure that the laser power supply and laser housing are electrically grounded before electrical power is applied.
- Avoid pointing the laser in any direction where a person could stare into the beam.
- Align the beam at a height below or above the normal eye level.
- Never leave an operating laser unattended.
- Never reflect a laser beam off a mirror or any other polished reflective surface indiscriminately.

APPENDIX B

LASER SPECIFICATIONS

The following specifications for lasers are furnished as a guide only and not as an endorsement of any make of laser. It is the responsibility of of concerned individuals to test and evaluate the lasers to determine which are best suited for their individual applications.

SUGGESTED ALIGNMENT LASER SPECIFICATIONS

Figures B-1 and B-2 show what is commonly called the alignment laser. This group of lasers conforms to National Aircraft Standards (NAS). They have a cylindrical housing that is either a ground and hardened surface throughout or they have hardened steel mounting rings that are ground. The diameter of the barrel or of the mounting rings is held to a tolerance of 2.2498 to 2.2493 inches. This is the same diameter as the housing of the alignment telescope. Therefore, the tooling laser will fit any of the optical tooling alignment accessories that were designed around the NAS standards for the alignment telescope. In most cases, the alignment lasers will replace the alignment telescope without any additional costs in support accessories. The alignment laser is well suited for the precision alignment required for machinery and shaft installation.

Some alignment lasers have modulated laser beams. The modulation frequency is 10 kHz and its purpose is to eliminate ambient light interference with the electronic targets. Also, some lasers use autoreflection and others use autocollimation. Autocollimation is more accurate at closer ranges, is sensitive to angular measurement, and is not responsive to displacement.

Suggested specifications are:

- Output: 1 milliwatt⁶
- Outside barrel diameter: 2.2498 $\begin{smallmatrix} +0.0000 \\ -0.0005 \end{smallmatrix}$ inches⁷

⁶The output of most lasers can be adjusted. Also, a neutral density filter can be used to reduce power output.

⁷This specification applies to the whole barrel or to mounting rings. These surfaces must be hardened for wear resistance.

- Beam concentricity: ± 0.001 inch
- Thermostable
- Sealed against environment
- Ruggedly constructed to prevent mirror shift during normal shipyard use
- Power cord to laser shielded against accidental cutting and mounted integrally to the laser
- Long-life laser tube with at least a 1-year warranty.

The power pack of the laser should be small, rugged, adequately fused, and have indicator lights. The indicator lights provide a safety factor since they indicate when the power pack is energized and when the laser is energized. Power packs available can be used with a 117-volt ac source; others can be operated with 12-volt batteries.

New models of the electronic detectors and their readout boxes make precision alignment easier and more accurate than was previously experienced. Based on this new advance of laser detector design, suggested specifications are:

- Easily readable meters (Figures B-1 and B-2) indicating horizontal and vertical displacement.
- A range selection switch to read in 0.001- to 0.005-inch increments.
- A light that indicates when the laser beam is striking the detector. This is usually called an acquisition light. The light is necessary for longdistance work when the operator cannot see his detector very well because of the distance. If both the meters read zero and the laser beam was not striking the detector, he may erroneously assume the laser beam is centered on the detector. The acquisition light eliminates this problem.
- Automatic gain control This feature prevents change in laser output power from affecting the readout on the meter. Thus, the unit would not require calibration each time it was used or when the beam was passed through a prism or other glass.
- Two readout modes (fast and slow) are useful features.

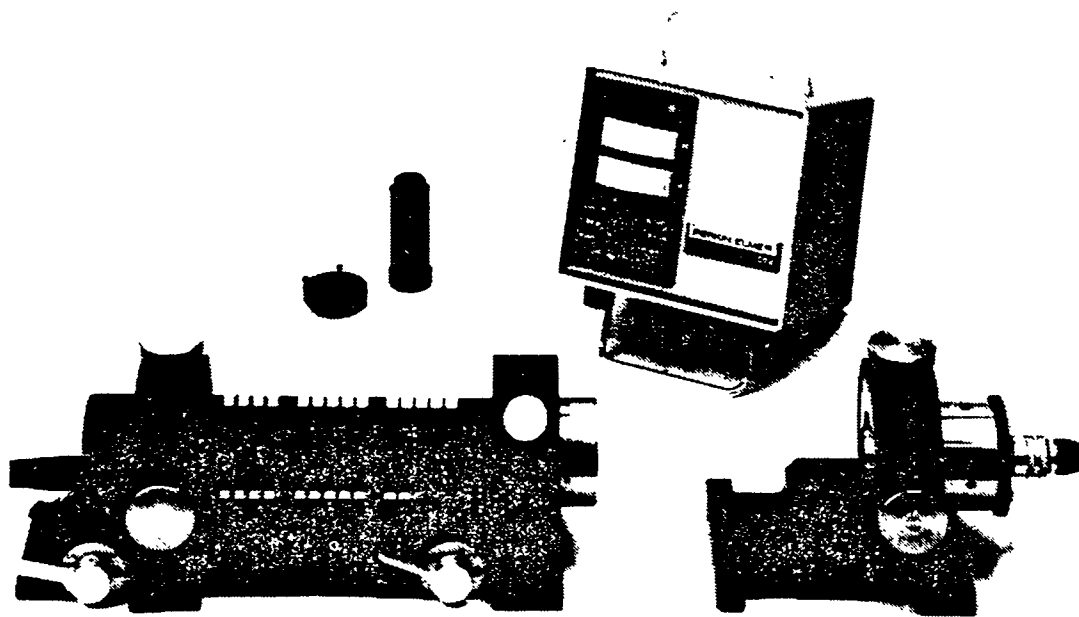


Figure B-1: Alignment Laser

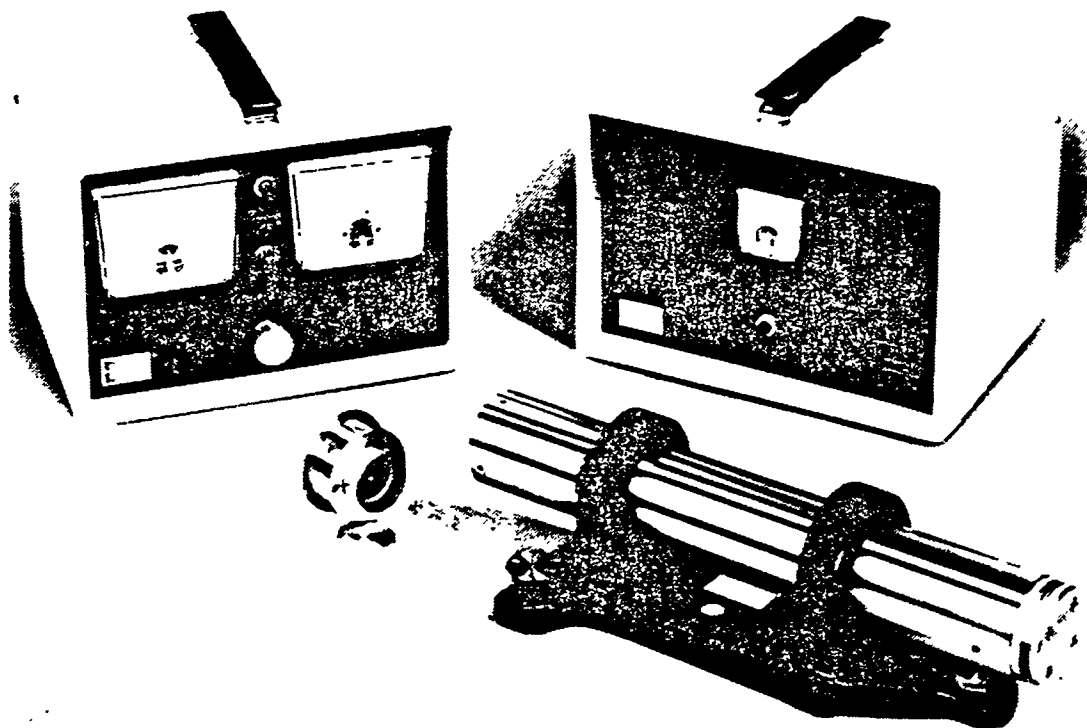


Figure B-2: Modulated Alignment Laser

- An integrating or time-delay readout system. This feature “smooths” out the jumping of the laser beam due to vibrations and changes in air density across the path of the beam.
- The readout box should be equipped with jack plugs so the readings can be recorded on a strip chart or other recording devices. This is a valuable feature for recording shaft alignment for customer information, etc.; for measuring the warping of a ship section over a period of time; or for recording changes in ship structure after launching.
- The readout box should be equipped to operate from 12-volt battery or 117-volt ac power sources.

SUGGESTED SPECIFICATIONS FOR SIMPLE LASER

General specifications for the simple laser (Figure B-3) are:

- Barrel should be cylindrical in shape.
- The power output should be 1 milliwatt.
- The laser must be of rugged construction and be able to withstand the abuse of the shipbuilding environment.
- The electrical cable from the power pack to the laser must be shielded to prevent accidental cutting. The cable must be made an integral part of the laser housing.
- The laser must be sealed against the out-ofdoors environment.
- The laser tube should have at least a 1-year warranty.
- The laser beam diameter for the lower cost lasers are small, being about 1 or 2 millimeters (1/16 inch) in diameter. The beam spreads to 1 inch at 100 feet. Some manufacturers make a collimating lens system that attaches to the laser housing. This collimating unit expands the beam about 10 times and collimates it.
- Laser beam divergence is usually listed in milliradians, and most low-cost lasers have divergence of about 0.6 to 0.9 milliradians. The smaller this value, the better. For instance, a 0.85 -milliradian beam divergence would produce about a 3-inch diameter beam spot at 300 feet, whereas a collimated beam of 10 millimeters would be about 13 millimeters (1/2 inch) at 300 feet. At 50 feet, the 0.85-milliradian divergence beam would be 1/2 inch in diameter; thus, it depends on application of the laser.
- The laser must be operable in any position.

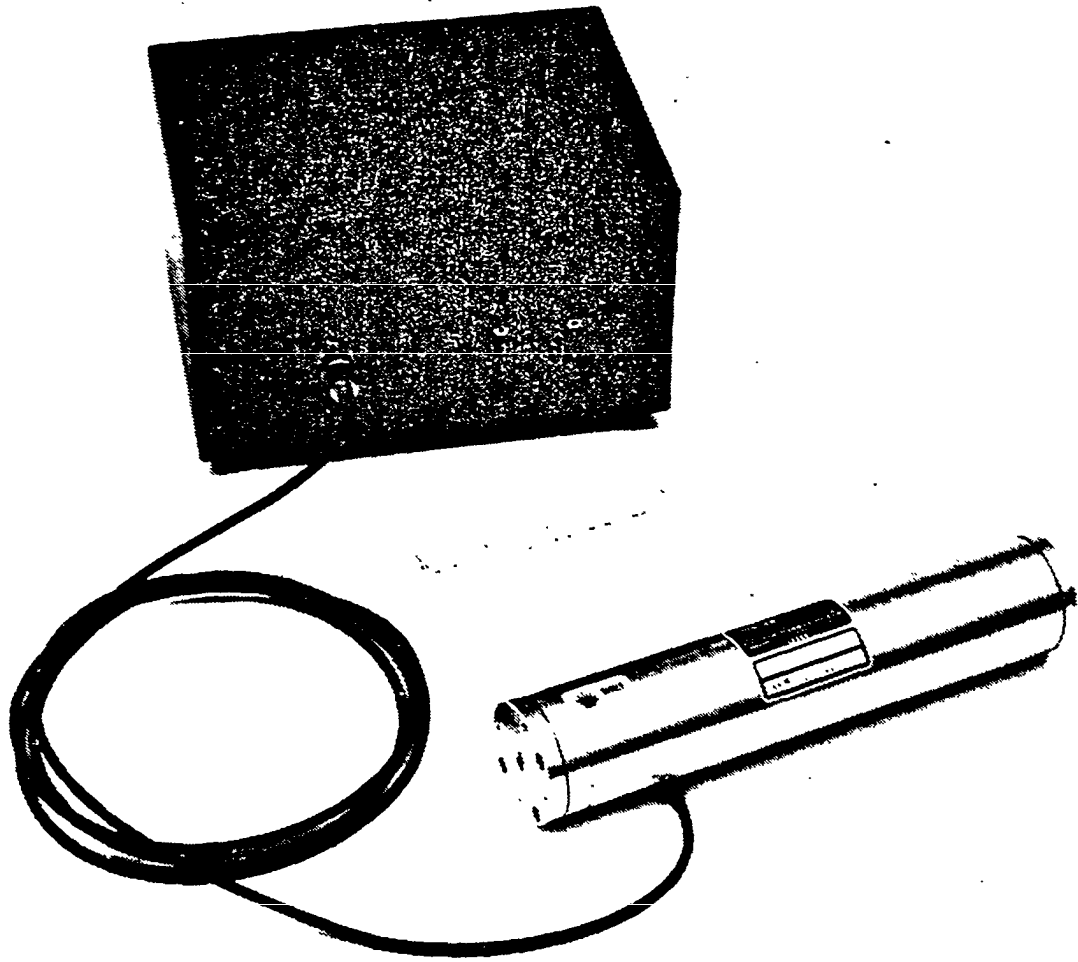


Figure B-3: Simple Laser

The power pack for the laser can be battery operated (12 volts) or plugged into a 117-volt ac line. These units must have indicator lights and be sealed from the environment. They should be lightweight and portable.

Other laser instruments such as those designed for construction work, i.e., storm sewer layout, bridges, and underwater tunnels, should be investigated. Also, there are some laser devices that rotate the beam. The speed of rotation can be controlled. A rapidly rotating beam will appear as a line. These units will project the beam in any orientation; thus, could be used in false ceiling layout, etc.

The following list is only a sampling of laser manufacturers. Consult the *Laser Supplies Directory*, which is available in most libraries. for a complete listing of laser manufacturers. The *Thomas Registry* is another source for this information.

- | | |
|--|---|
| ● Keuffel & Esser Company
20 Whippany Road
Morristown, New Jersey 07960 | ● Coherent Radiation Company
3210 Porter Drive
Palo Alto, California 94304 |
| ● Laser Alignment & Control Inc.
P.O. Box 1093
Palo Alto, California 94302 | ● Constructors Supply Company
15629 Clanton Circle
Santa Fe Springs, California 90670 |
| ● Petrologic Instruments
143 Harding Ave.
Bellmawr, New Jersey 08030 | ● C. W. Radiation
111 Ortega Ave.
Mt. View, California 94040 |
| ● RCA
New Holland Ave.
Lancaster, Pennsylvania 17604 | ● Electro Optics Associates
901 California Ave.
Palo Alto, California 94303 |
| ● Spectra-Physics Company
1250 W. Middlefield
Mt. View, California 94040 | ● W. & L. E. Gurley Company
Troy, New York 12181 |
| | ● Hughes Aircraft Co.
Electron Dynamics Div.
Torrance, California 90509 |

These laser manufacturers provided the photographs used in this document.

APPENDIX C VISUAL TARGETS

The visual target and the stick-on targets are shipyard-manufactured items. The size of the targets is dependent upon the distance of the target from the observer and the size of the laser beam at the target site. Tables C-1 and C-11 provide the necessary data for Fabrication of the targets. An attempt has been made to limit the number of sizes required for the various distances. Thus, as seen in Tables C-1 and C-II, three target sizes will span the total distance of 400 feet. Figures C-1, C-2, and C-3 provide the fabrication instructions for the targets.

*Table C-1
Data for Manufacture of Visual Target of Figure C-1*

Distance of laser to target (feet)	Dimension A (inches)	Dimension B	Dimension C (inches)	Dimension D (inches)
10	0.50	(a) ↑	3.00	0.50
20	0.50		3.00	0.50
30	0.50		3.00	0.50
50	0.50		3.00	0.50
75	0.50		3.00	0.50
100	0.50		3.00	0.50
125	1.0		5.00	1.50
150	1.0		5.00	1.50
175	1.0		5.00	1.50
200	1.0		5.00	1.50
250	2.00	↓ (a)	10.00	2.00
300	2.00		10.00	2.00
350	2.00		10.00	2.00
400	2.00		10.00	2.00

^aDimension B is a measurement of the diameter of the laser beam, at the target-site, plus 1 millimeter. A flat, white card is ideal for spotting the laser beam for measurement.

Table C-II

Data for Manufacture of Stick-on Visual Target of Figure C-2

Distance of laser to target (feet)	Dimension A (inches)	Dimension B	Dimension C (inches)	Dimension D (inches)
10	1.5	(a)	(b)	(c)
20	1.5			
30	1.5			
50	1.5			
75	1.5			
100	1.5			
125	2.5			
150	2.5			
175	2.5			
200	2.5			
250	5.0			
300	5.0			
350	5.0			
400	5.0	(a)	(b)	(c)

^aDimension B is a measurement of the diameter of the laser beam, at the target site, plus 1 millimeter. A flat, white card is ideal for spotting the laser beam for measurement.

^bDimension C is optional but must be at least twice Dimension A.

^cDimension D is fixed by the thickness of the prismatic plastic material, usually 1/8 inch.

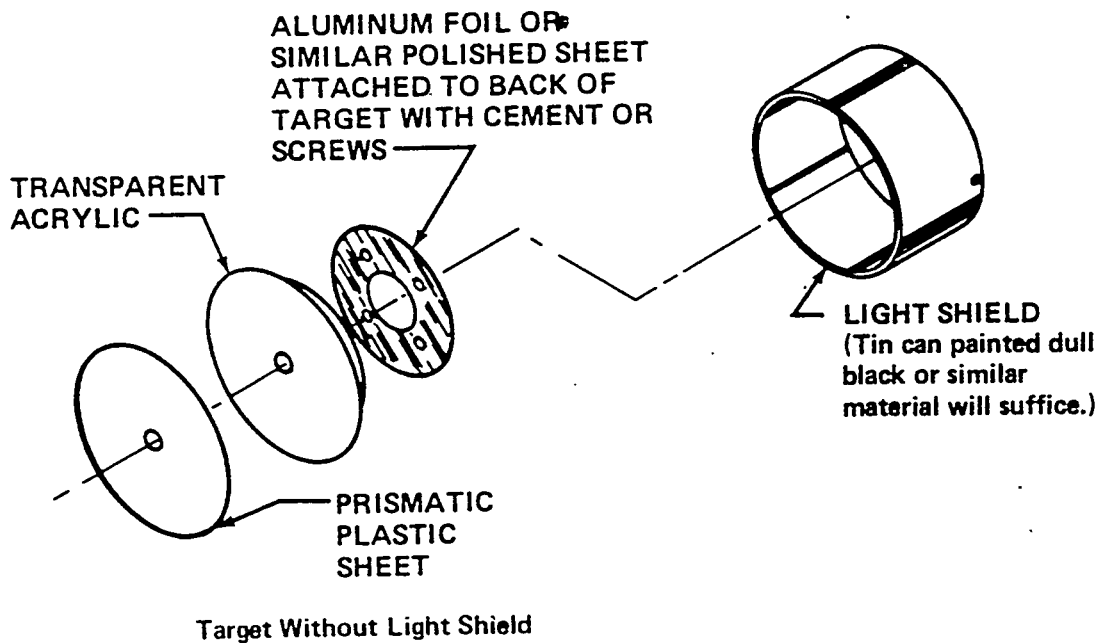
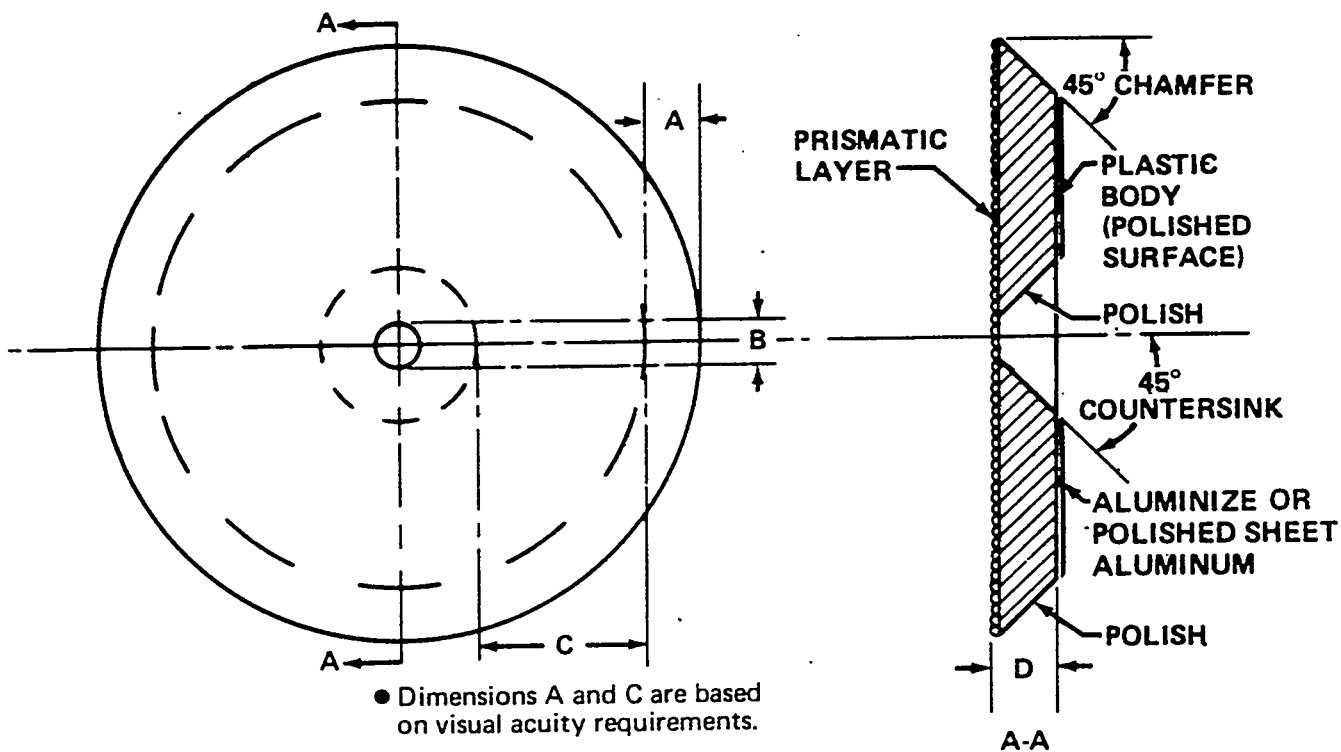


Figure C-1: Visual Target

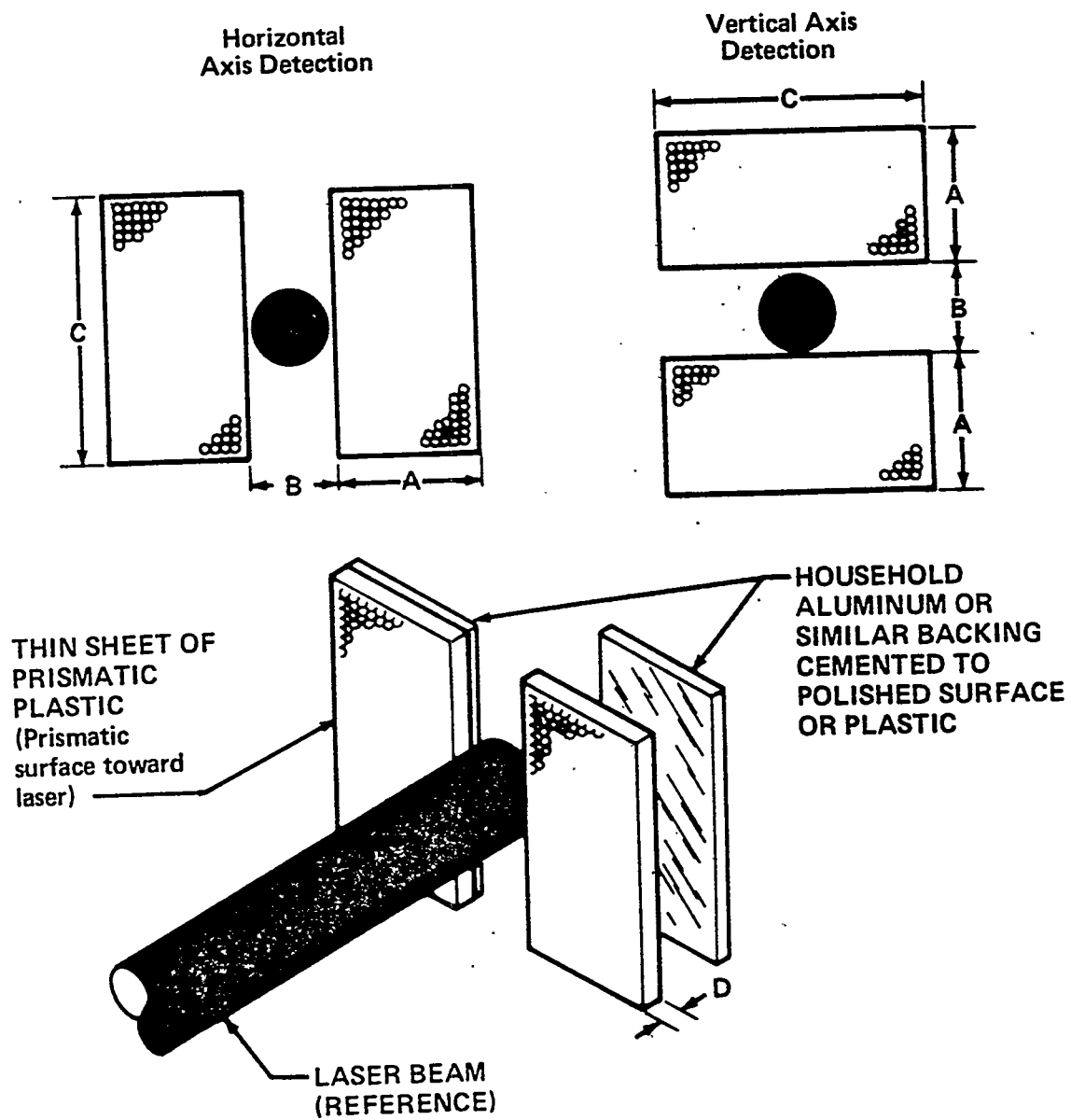
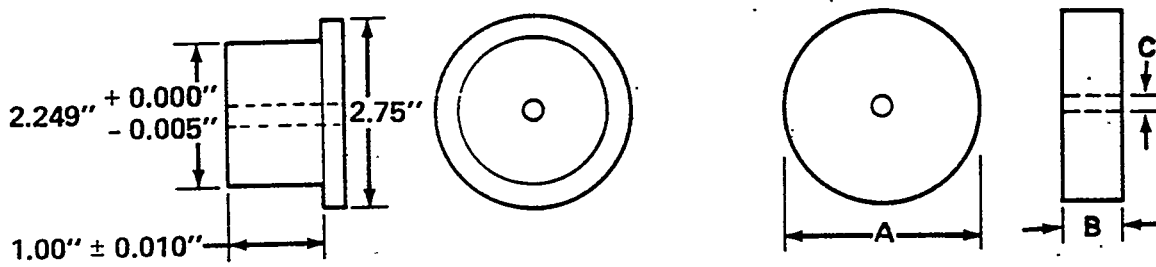
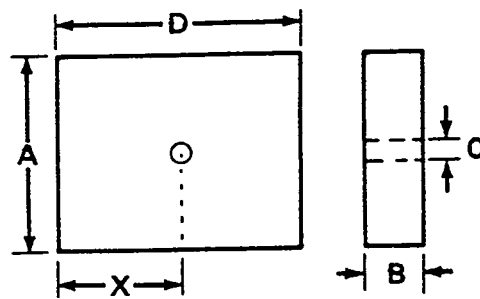


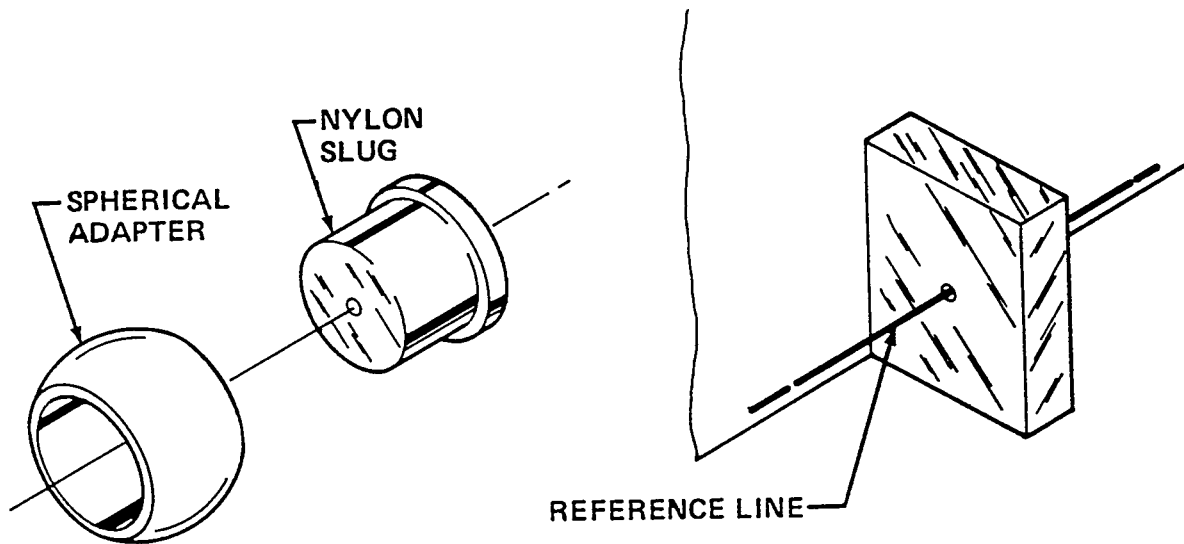
Figure C-2: Stick-On Visual Targets



Nylon Slugs for Use in Spherical Adapter



Nylon Slug for Indexing



- Dimensions A, B, and D are optional and depend on application.
- Dimension C is typical of all center holes and should be 1 millimeter larger than the diameter of the laser.
- Dimension X represents a gage dimension where the nylon target is placed against a reference.

Figure C-3: Nylon Visual Target (for Close-Range Work Within 30 Feet of Laser)

G L O S S A R Y

ALIGNMENT LASER: A specially manufactured laser where a helium-neon laser tube is mounted in a cylindrical housing that is machined to NAS specifications. The NAS specifications are specific dimensions called out for fabrication of the outer diameter of the laser housing. The laser beam is centered on the mechanical axis of the housing to within 0.001 inch. The laser beam diameter remains fairly constant over the designed working distance of the laser. It is used for precision alignment.

ALIGNMENT TELESCOPE: A precision refracting telescope containing cross hairs where the optical and mechanical axes are made coincident. The optics are mounted in a steel cylindrical housing machined to NAS specifications. It usually has two optical micrometers. It is used in precision alignment work.

ANGSTROM UNIT: A unit of measurement of wavelength of light. One Angstrom unit (\AA) equals one hundred millionth of a centimeter or 10^{-10} meters. Helium-neon laser light has a wavelength of 6328 Angstrom units.

AUTOCOLLIMATION: A technique used in alignment whereby a light is reflected back on itself from a mirrored surface to obtain perpendicularity to that surface. The term is used with alignment telescopes and alignment lasers that are equipped with autocollimating attachments. Thus, an autocollimating laser can detect the laser light reflected back into it from a mirror surface. If the mirror is tilted, the returning beam will be offcenter on the photo cell in the laser, thus indicating an angular error.

AUTOREFLECTION: Autoreflection is similar to autocollimation as far as laser application is concerned: i.e., laser light is reflected back from a mirror and is detected inside the laser housing. However, the autoreflecting laser does not use lenses in the autoreflecting head, as does the autocollimating laser; thus, it is not a true angular measuring device as is the autocollimating laser.

BEAM BENDING: The term “beam bending” is applied when the direction of the laser beam is changed. A mirror or prism, etc., when placed in the path of a laser beam, will bend the laser beam in any desired direction.

BEAM DIVERGENCE: Beam divergence pertains to the spreading of the laser beam as it leaves the laser. Precision lasers employ additional optics to control the spread of the beam.

BEAM, LASER: The laser beam is made up of concentrated rays of light emitted from the laser source.

BEAM SPLITTER: The beam splitter is an optical device that splits the beam of light into two or more beams. The beam splitter can be designed so that the beam can be split into two equally intense beams or into unequally intense beams.

COHERENT RADIATION: The term “coherent radiation,” as applied to laser light, refers to the individual light rays that make up the laser beam. All the rays are in phase with each other. This as compared with regular red light as it is emitted from a source where the individual rays of light are out of phase with each other.

COLLIMATED LIGHT: Collimation pertains to parallelism, thus, a collimated light would have all of the individual rays parallel with each other. Light reaching the earth from a distant star is said to be collimated since only the parallel light rays would reach the relatively small surface of the earth.

ELECTROMAGNETIC RADIATION: Electromagnetic radiation pertains to all forms of radiant energy from the extremely short wavelength cosmic rays to the extremely long wave radio broadcasting signals. The visual spectrum occupies a very small portion of this vast spectrum. Helium-neon laser light is included in the visual spectrum at the lower end (longer wavelength) of the visual spectrum.

FIRST-SURFACE MIRROR: A mirror that has the outside surface of the glass aluminized to reflect light rather than the back side of the glass, as is common in household mirrors. The first-surface mirror is usually precisely ground optically flat on its coated side.

FLUORESCENCE: Simply stated, fluorescence is the conversion of invisible radiation, i.e., ultraviolet, to visible white light. Thus, in a fluorescent tube, white light is produced when the ultraviolet light radiation strikes the phosphor coating on the inside of the glass envelope.

INFRARED: Infrared is a term used to define the portion of the electromagnetic spectrum that lies between the visual zone and the short radio waves.

INTERFEROMETER: An instrument that uses interference bands created when two sections of a split light beam have been made to interfere with each other is called an interferometer. In the case of the laser light interferometer, the light bands are spaced approximately 12-1 /2 millionths of an inch.

LASER: The word “laser” originated from the process used to create the extremely bright light, i.e., light amplification by stimulated emission of radiation. The term “laser” is also applied to nonvisible radiating sources such as the carbon dioxide laser.

LASER LEVEL: This is a leveling instrument where a laser tube is attached to a conventional telescope. The beam is used as a reference. Some models use only a laser tube. The laser beam in this case is made parallel with the axis of the spirit level.

MECHANICAL AXIS: The mechanical axis is a term used in optical work to define the mechanical center of cylindrical housing or a lens: It is used in conjunction with the optical axis when referring to the location of the lens elements of an alignment telescope or a cylindrical laser unit. The optical axis need not always be at the mechanical axis, as in the case of simple lasers or telescopes.

MILLIWATT: The milliwatt, as its name implies, is one thousandth of a watt. Lasers used in alignment have their output rated in milliwatts of power.

MIRROR, FIRST-SURFACE: See “first-surface mirror” in this glossary.

“MONOCHROMATIC: Monochromatic is a term derived from the Greek words monos, meaning single, and chroma, meaning color. Thus, the helium-neon laser beam is monochromatic or a one-color light beam that is deep red and has a wavelength of 6328 Angstroms.

NAS: The National Aerospace Standard (NAS) is a specification written by the Aerospace Industry Association (AIA) of America. The NAS standard for alignment lasers and telescopes defines the exact dimensions of the outer diameter of the cylindrical housing.

OPTICAL AXIS: The optical center of a lens or lens system is called the optical axis. The optical center may or may not be coincident with the mechanical center.

PARALLAX ERROR: This is a term given to the angular error that results when two in-line objects are viewed from two different positions.

PHOTO CELL: The photo cell is a light-sensitive electronic device that produces a small current when a light strikes its surface. In laser alignment work, the electronic detectors (targets) use silicone photo cells.

PRECISION LASER: This is another name for the alignment laser.

QUADRANT CELLS: The electronic, detectors used in laser alignment work have either one large silicone cell divided into four quadrants or four single cells arranged in a quadrant.

REFERENCE POINT: A point located with specific dimensions. A reference point has a three-dimensional position or location, i.e., elevation, longitudinal, and lateral, from the surrounding structures.

SILVERED SURFACE: This term is commonly applied to the reflective coatings used in mirrors. Silver is used in specific types of mirrors used in scientific work, but most mirrors use aluminum coatings.

SURVEYOR'S LEVEL: This is an optical instrument that uses a telescope with its optical axis adjusted parallel to a spirit level on the leveling base of the instrument.

TOOLING DOCK: The tooling dock is a rigidly fixed structure where optical instruments (lasers, alignment telescopes, transits, etc.) are precisely located to perform repeated alignment tasks.

TOOLING LASER: Another name for alignment and precision lasers.

TRANSIT LASER: The transit laser has a cylindrical laser attached to the conventional transit telescope. Some models have the laser beam projecting through the optical telescope. Other models have the laser beam projecting parallel to the optical axis of the telescope.

ULTRAVIOLET: The term "ultraviolet" is the name given to the invisible portion of the electromagnetic radiation spectrum, which is located just beyond the visible violet of the visual spectrum.

VISUAL TARGET: Any target not used for electronic sighting is a visual target.

laser beam detector. Rods of various length
desired length measuring rod.